



The influence of extrusion processing on the nutritional value of barley for weanling pigs and broiler chickens

by Annette Gale Heryford

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Animal Science

Montana State University

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Abstract:

The purpose of this study was to determine the effect of the extrusion process on the nutritional quality of barley. Three barley cultivars (Hector, Franubet and Washonupana) were used in the preparation of raw and extruded diets. Hector is a covered barley and the other two are hull-less. Barleys were analyzed for their chemical composition, physical measurements and tested in meal diets of weanling pigs and broiler chicks in the ground raw or extruded state.

Raw barley diets consisted of 70% raw ground barley plus 30% extruded soybeans, blended with minerals, vitamins and antibiotics. Extruded diets were made from a mixture of 70% barley plus 30% soybeans, extruded together in an InstaproR extruder (Triple "F", Inc., Des Moines, IA 50322). After extrusion they were blended with minerals, vitamins and antibiotics as with the raw diets. Soybeans were necessary to facilitate the extrusion process. The average calculated fat value of the extruded barley-soybean mixtures was 7.8% However chemical analysis of the extruded barley-soybean mixtures showed an average fat value of 2.2% This low value may have been a result of amylose-fat complexes formed during extrusion, which made the fat less extractable by conventional chemical methods. The extruded barley-soybean mixtures showed higher viscosity readings than the raw barley-soybean mixtures. It is possible that extrusion increased the soluble beta-glucans at the expense of the insoluble, which may have increased viscosity.

Chick growth trials, using 1-day-old broiler chicks, indicated a significant difference between raw and extruded barley-soybean diets for average weight gain and feed/gain ratios. Results of chick trial 1 showed that chicks fed the extruded barley-soybean diets exhibited significantly lower weight gains ($p = .0001$) and significantly higher feed/gain ratios ($p = .0001$) than chicks fed the raw barley-extruded soybean diets. The addition of beta-glucanase to diets in chick trial 2 improved weight gains over trial 1, but chicks fed the extruded diets still gained significantly less ($p = .0004$) and had significantly higher feed/gain ratios ($p = .0039$) than chicks fed raw barley-extruded soybean diets. The addition of supplemental lysine to the diets decreased weight gains significantly ($p = .0017$).

Pig growth trials, using 3-week-old pigs showed no significant difference in weight gains ($p = .46$), feed/gain ratios ($p = .83$) or feed consumption ($p = .67$) between pigs fed raw barley-extruded soybean diets and pigs fed extruded barley-soybean diets.

It is concluded that the extrusion process reduces the feed value of barley for broiler chicks from 0-21 days without any apparent effect on the feed value for weanling pigs, and that the extrusion process has an influence on the nutritional value of a feed, but further studies are needed to determine the exact nature of these influences.

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A thesis submitted in partial fulfillment
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ABSTRACT

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It is concluded that the extrusion process reduces the feed value of barley for broiler chicks from 0-21 days without any apparent effect on the feed value for weanling pigs, and that the extrusion process has an influence on the nutritional value of a feed, but further studies are needed to determine the exact nature of these influences.

INTRODUCTION

Cereal grains such as wheat, maize, rice and barley have been an important staple in the human food chain both as a food for people and as a feed for their livestock since human civilization began. At the very beginning of human history, barley (Hordeum vulgare L.) was the most important crop grown in terms of amount grown and monetary value (Harlan, 1968), but was gradually replaced in importance by grains such as wheat and maize.

Today, barley is the world's fourth most important crop, ranking behind wheat, maize and rice (Mackey, 1981). Its primary use is for animal feed, with secondary uses in the human food and brewing industries, even though barley is high in nutritive value and can be grown over a wider range of environmental conditions than any other grain. Barley and barley by-products have been manufactured into numerous human and animal foodstuffs and research continues to expand our ability to use barley to its fullest potential.

Extrusion is a method of cooking in which a food mixture is placed under heat, moisture and pressure, and after an appropriate amount of time, is forced through a small opening. The product is then cooled and cut into desired shapes or sizes. The literature available indicates that this cooking method has an influence on the molecular structure of some of the food components, especially protein and starch. This influence appears to affect the digestibility of the components, positively in some cases, negatively in other cases. The information available on the influence of extrusion cooking on barley

and barley-based products is limited. The focus of this research was to determine if extrusion cooking has a significant effect on the nutritional components of a barley-based diet, and if so, if this effect is capable of significantly influencing the digestibility of the diet for weanling pigs and broiler chicks.

The general objectives of this study were to:

1. Determine gross chemical composition of four different barleys in the raw and extruded state.
2. Determine the physical qualities of these barleys.
3. Determine growth and feed efficiency rates of broiler chicks fed the raw and extruded barleys.
4. Determine the growth and feed efficiency rates of weanling pigs fed raw and extruded barleys.

LITERATURE REVIEW

Introduction

Barley is one of the world's most ancient cereal grains, although its exact origin is uncertain. The earliest carbon-dated remains of cultivated barley discovered thus far are from a site in Iran, and date back to around 7900 B.C. (Harlan, 1968). However, a more recent, but unverified study by Wendorf et al. (1979), places the origin of barley to around 17,000 B.C. along the Nile Valley (Poehlman, 1985). The oldest remains are all of the two-rowed types, but by at least 6000 B.C., six-rowed types were being cultivated. It is believed that the original ancestor of all barleys is a wild form (*Hordeum spontaneum*) which is found primarily in the Middle East. This wild barley has not been well characterized but is a two-rowed barley which undoubtedly occurs in varying degrees of hardness, grain size, color, disease resistance, etc. Spring and winter forms are known and hooded varieties are found (Briggs, 1978).

The major use of barley is for animal feed. The second largest use is for malting. Of less significance is barley's use for human consumption in the form of whole grain, pearled barley and flour. Barley has traditionally been a grain associated with a lower socioeconomic status, and as such is not the grain of choice for human food even though barley is high in nutritional quality, has exceptional organoleptic attributes and has the ability to be grown over a wider environmental range than any other cereal.

Barley Kernel Structure and Composition

Physical Characteristics

Barley comes in a wide variety of forms, shapes and sizes, however all barleys contain some common components. In many cultivars, the kernel is covered by an outer husk consisting of the palea and lemma, but in some lines, this husk separates from the kernel, leaving the naked or hull-less kernel. The strength of the attachment of the hull at maturity depends on the variety of the barley and the conditions under which it is grown (Briggs, 1978). Naked kernels contain relatively higher proportions of fat, protein and starch due to a reduction in the fiber contributed by the hulls (Newman and McGuire, 1985). Below the husk lies the pericarp, the aleurone layer, the starchy endosperm and the embryo, which is partially exposed. The pericarp acts as a protective covering for the kernel. The starchy endosperm makes up the majority of space in the kernel and provides nutritive tissue for the developing embryo. The starchy endosperm is composed of differing types of dead tissue. A layer of cell walls without cellular contents, crushed together, lies toward the base of the endosperm, while the central portion of the endosperm consists of thin-walled parenchyma cells packed with varying sizes of starch grains. The starch grains lie in a proteinaceous matrix associated with fragments of amyloplasts in which the starch granules were first formed. The starchy endosperm adjacent to the aleurone layer contains more protein and less starch. The starch which does reside here tends

to consist of smaller granules. When cut across, the endosperms of immature kernels take on a hard, flinty appearance, while plump, mature grains have a chalky or floury look. This chalky appearance is probably due to the presence of tiny cracks around the starch grains which hold air (Briggs, 1978).

The aleurone covers the endosperm and contains protein bodies and enzymes responsible for the digestion of the starchy endosperm underlying it. The embryo, which lies in the base of the kernel develops into the young plant as the seed germinates (Reid, 1985).

Physical characteristics can be used to distinguish barley varieties from each other. One of the most obvious traits is whether the barley is two-rowed or six-rowed. These terms refer to the number of rows of grain visible on the plant. In two-rowed barleys, the grains are symmetrically arranged. In a six-rowed barley, the median grains are symmetrical while the lateral grains are unsymmetrical with either a right or left-handed bias (Briggs, 1978). Six-rowed barleys take on an overall look of "fullness" when compared to two-rowed barleys, however larger, heavier kernels are usually produced by the two-rowed varieties (Newman and McGuire, 1985) and two-rowed varieties contain an average of 1 to 2% more protein than the six-rowed varieties (Pomeranz et al., 1973).

Chemical Composition

Carbohydrates. Starch comprises 63-65% of the weight of a plump, two-rowed barley grain, and makes up 85 to 89% of the endosperm tissue (Briggs, 1978). Generally, the starch found in the endosperm is approximately 74 to 78% amylopectin, with a mixture of alpha-1,4-glucopyranose units and alpha-1,6-linkages. Amylose makes up the remainder of the starch, and contains straight chains of D-glucopyranose units with alpha-1,4 linkages (Briggs, 1978). However, some cultivars contain starch which is 100% amylopectin (Goering and Eslick, 1976), and cultivars with a 1:1 ratio of amylose to amylopectin have been found (Merritt, 1967).

Other carbohydrates are present in the kernel and have been quantified in both the aleurone and inner endosperm areas. The cell walls in the aleurone layer are comprised of approximately 44% xylose, 29% glucose, 23% arabinose, 2% mannose, and 2% galactose. The two main polymers in these cell walls are arabinoxylans (60%) and mixed-linked beta-glucans (20%). Some protein and phenolic acids are also present (Bacic and Stone, 1981). The carbohydrate portion of the endosperm cell walls consists of approximately 74% D-glucose, 13% D-xylose, 10% L-arabinose and 2.5% D-mannose (Ballance and Manners, 1978).

Cellulose, hemicellulose and lignin also occur in barley, and make up what is generally referred to as the crude fiber portion. Hulled barleys contain 4 to 8% crude fiber, while the hull-less lines average 2% or less crude fiber (Newman and McGuire, 1985).

Barley also contains a significant amount of hydrocolloidal carbohydrates collectively called beta-glucans, which form part of the endosperm, and are a major component of the endosperm cell walls.

Lipids. The lipid content of barley is low compared to corn and oats, and accounts for only a small fraction of the dry matter (Briggs, 1978). Lipids which do exist in barley are found primarily in the embryo, hull, and the endosperm. A study on the lipids of Prilar (a hull-less barley) showed that the endosperm contained 77.1%, the embryo contained 17.9% and the hull contained 5% of the total lipids in the barley (Price and Parsons, 1979). The amount of lipids in barley varies depending on the cultivar and the environmental conditions under which the barley is grown (Newman et al., 1974; Fedak and De LaRoche, 1977). The lipids in barley are primarily triglycerides, the majority of which are palmitic acid and the unsaturated fatty acids, oleic, linoleic, and linolenic acids. Linoleic acid is the principal fatty acid of the barley kernel (Briggs, 1978; Price and Parsons, 1979).

Protein. The composition and the amount of protein have a major effect on the nutritional quality of a barley. The proteins found in grains were originally classified according to their solubility in salt, hot ethanol, water or alkaline extracts, as globulins, prolamins, albumins and glutelins, respectively (Osborne, 1924).

The major storage proteins are prolamins, which in barley are called hordein (Kirkman et al., 1982) and are found primarily in the endosperm. Hordein is poor in lysine, but has a major effect on protein quality by either lowering or raising the total lysine level in the kernel. An increase in hordein in barley reduces the percent of lysine in the total protein.

Albumins and globulins make up 15-30% of the total kernel nitrogen, and are mainly metabolic proteins, although some evidence indicates they may be used as storage proteins to some extent. These are found mainly in the embryo and the aleurone layer, and are thought to be high in nutritional value since they are rich in lysine and threonine (Shewry et al., 1984).

Glutelins function primarily as structural proteins and are associated with membranes and matrix proteins (Mifflin and Shewry, 1979; Shewry et al., 1984), but they may have some metabolic roles as well (Shewry et al., 1984).

As protein content increases, amino acid nitrogen also increases, although the change in individual amino acids is not linear (Pomeranz, 1974). Generally, an increase in protein coincides with a rise in all amino acids except cystine up to a particular protein level, after which most amino acid levels tend to decrease except glutamic acid, proline and phenylalanine, which increase. Lysine exhibits the greatest change after the maximum protein level is reached, decreasing nearly 24% (Newman and McGuire, 1985).

Other Nutrients. Barley is an excellent source of many of the B-complex vitamins, especially thiamin, pyridoxine, riboflavin and pantothenic acid. Barley also contains a high percentage of niacin, but because it is complexed with certain proteins, only about 10% of the niacin appears to be available to monogastrics (Hoppner et al., 1968). Some biotin and folacin can be found in barley as well as some vitamin E. The barley kernel itself contains no carotene or vitamins A and D (NRC, 1979).

Barley generally has an ash content of 2 to 3% with hull-less barleys being the lowest in ash. The mineral concentration of a particular barley is influenced by soil type and climatic conditions, but according to Owen et al., 1977, the principal mineral elements of barley are potassium and phosphorous, with smaller amounts of chlorine, magnesium, sulfur, sodium and calcium. Hulled barleys contain more calcium and silica than the hull-less lines, presumably because hulls contain a greater concentration of these elements (C. W. Newman, unpublished data).

Beta-glucans. Beta-glucan is a general term used to describe compounds of two or more beta-D-pyranose molecules hooked together in a beta configuration. (Preece and McKenzie, 1952; Bourne and Pierce, 1972) Beta-glucans are not a single chemical entity, but rather a family of substances which vary in molecular structure and molecular size. (Bathgate and Dalgliesh, 1975). They are a constituent of the cell walls surrounding the starch granules in the endosperm (Bathgate et al., 1975) and are present in substantial quantities in barley and

oats, with barley containing 2-10% beta-glucans, and oats 2-4%. (Bamforth, 1982). Rye contains a smaller percentage of beta-glucans, and corn and wheat even less than rye. (Preece and Mackenzie, 1952; Lance, 1984). Beta-glucans exist in mixed 1,3:1,4 linkages, with approximately 70% 1,4 linkages and 30% 1,3 linkages (Bourne and Pierce, 1972). From recent studies, it appears that about 90% of the water soluble beta-glucans in barley endosperm are constructed of celotriosyl and celotetraosyl units connected with beta 1,3 linkages, with the remainder consisting of beta 1,4 linkages. (Woodward et al., 1983).

The percentage of beta-glucans found in barley is dependent upon genetics and the environment. (Bourne and Pierce, 1972; Coles, 1979). Barley grown under hot, dry conditions generally has a higher beta-glucan content while that grown under wet conditions contains a lower percentage. (Bendelow, 1975). Beta-glucan concentration appears to increase during the first stages of germination, however at this time the molecular weight of the beta-glucan apparently decreases, indicating perhaps that enzyme activity is increasing. (Bourne and Pierce, 1972; Prentice and Faber, 1981). The variety of the barley also influences the beta-glucan content, (Prentice and Faber, 1981) as does the stage of ripeness of the grain at harvest and the storage method used. (Thomke, 1972; Hessleman and Thomke, 1982).

The formation of beta-glucans in the kernel occurs when beta-glucan synthases use the sugar nucleotide uridine diphosphate glucose (UDPG) or guanosine diphosphate glucose (GDPG) (Montague and Ikuma,

1978; Henry and Stone, 1982). The concentration of either UDPG or GDPG appears to dictate the type of beta-glucan formed. With high concentrations of UDPG, beta 1,3 linkages are prevalent (Peaud-Lenoel and Axelos, 1970;) while when GDPG is used only beta 1,4 linkages are formed (Montague and Ikuma, 1978).

Beta-glucans are degraded mainly by four enzymes present within the seed. Endo-beta-1,3 glucanase is formed de novo during germination (Lance, 1984; Bennett and Chrispeels, 1972). Endo-beta-1,4 glucanases are present in very small amounts and are mainly active during germination. Their main activity occurs in the husk and pericarp during germination (Ballance and Meredith, 1974; Ballance et al., 1976). Endo-1,3;1,4 beta-glucanases, also called endo-beta-glucanase, is present only in the germinating kernel, and is absent in the mature grain (Luchsinger et al., 1958). Beta-glucan solubilase is responsible for removing beta-glucans from the cell walls of the endosperm, and is present in significant amounts in mature, intact grains. Its activity increases during steeping and germination (Bamforth and Martin, 1981). This solubilase appears to be a major factor in the initial release of the beta-glucan from the cell walls, a process which is then continued by the action of the remaining enzymes (Narziss, 1980). The combined activity of all four enzymes is capable of degrading the entire beta-glucan content of the barley kernel to oligosaccharides (Lance, 1984).

These beta-glucanases are generally inactivated at temperatures above 50C however, the endo-1,3 beta-glucanase may be sensitive to temperatures over 30C (Moffa and Luchsinger, 1970). The endo-beta-1,4 glucanase appears to be stable up to 60C (Moffa and Luchsinger, 1970).

All four beta-glucanases have optimal activity at approximately pH 5 (Preece and Hogan, 1956; Bass et al., 1953; Luchsinger et al., 1958). The endo-beta-glucanase complex appears to become more sensitive to heat at higher moisture contents (Luchsinger et al., 1958).

Barley is unique among the cereal grains in that the endosperm cell walls completely enclose the cell and thereby make cellular contents resistant to proteolytic and amylolytic enzyme activity. (Lance, 1984). When these cell walls are degraded, beta-glucans are released, and these non-starch polysaccharides contribute to nutritional problems in poultry and pigs as well as filtration problems in the brewing industry. (Lance, 1984; Bamforth, 1982; Hesselman, 1983; Hesselman and Aman, 1986). These same beta-glucans may have marked hypocholesterolemic effects in poultry and humans with lowered serum cholesterol concentrations. (Qureshi, 1980; Kirby et al., 1981; Andersson et al., 1984; Newman and Newman, 1987).

Poultry fed barley based diets experience reduced weight gains, lowered feed intake and sticky feces (Burnett, 1966; Laerdal et al., 1960; Hesselman, 1983), which have been attributed to the beta-glucan content. Degraded, solubilized beta-glucans apparently cause an increase in the viscosity of the intestinal fluid which restricts nutrient uptake and impairs water relationships in the gut. (Prentice and Faber, 1981). This increased intestinal viscosity is also related to decreased feeding performance of pigs (Lance, 1984). However, it should be noted that there may be factors other than soluble beta-glucans which contribute to reduced feeding performance, such as the

intact endosperm cell walls which protect the starch and protein from degradation by animal enzymes (Lance, 1984).

Beta-glucans are also implicated in problems in the brewing industry, such as reduced rate of wort filtration and haze formation (Bamforth, 1982).

The addition of enzymes to barley diets has been shown to improve performance of chickens and pigs. Hesselman et al. (1982) found that by increasing levels of beta-glucanase in the diet, live weight was increased 10-26%, and feed efficiency by 4.9 to 11%, and the dry matter of the droppings was significantly increased. The stickiness of the droppings was found to be greatly reduced and weight gains increased with the increasing addition of *Trichoderma viride* (an active source of beta-glucanase) to the diet, however this improved growth response plateaued off at a particular level (White et al., 1980). The addition of enzyme to some Japanese barleys also produced improved weight gains and feed efficiency (Hijikuro, 1983). It has been shown that the dry matter of chicken excreta decreases as viscosity of the diets increases (Gohl et al., 1978). Gain and feed efficiency of swine ratios improve with the addition of beta-glucanase enzymes to a barley-based diet (Thomke et al., 1980; Newman and Pepper, 1984). A swine feeding trial comparing Compana (CI 5438) and two hull-less isolines with or without supplemental beta-glucanase showed mixed response in animal performance to the enzyme. There were no effects in Compana and one hull-less isoline while the waxy isoline was improved by the enzyme supplement in terms of gain (7.0%) and feed efficiency (9.6%) (C. W. Newman, personal communication). Newman and Newman (1987) reported that waxy covered and

hull-less isolines of Compana had higher levels of beta-glucans and that the response of broiler chicks to beta-glucanase was greatest in the waxy types compared to the normal starch barleys. It appears that the breakdown of the beta-glucans in the barley with enzyme supplementation are the major cause for the improvement, since it is primarily the beta-glucans which are responsible for the increased viscosity in the intestinal fluids, and hence the decrease in nutrient uptake (White et al., 1981; Prentice and Faber, 1981). It has also been suggested that it is the molecular weight distribution of the beta-glucans which are primarily responsible for increasing intestinal fluid viscosity (White et al., 1981).

The evidence seems to indicate that hydrolysis of beta-glucans in solution reduces viscosity, and it is this lowered viscosity which allows for greater nutrient absorption, not the actual hydrolysis of the beta-glucans (White et al., 1981; Newman, et al., 1985).

Generally, four different methods of analysis have been employed to estimate the beta-glucan content of a grain sample. Absolute viscosity of an alkaline buffer extract can be determined by using a viscometer. A small glass ball is dropped through the sample, and its fall time recorded with a stop watch. The viscosity value of the sample can be calculated from this flow time relative to the flow time of distilled water (Coon et al., 1978). This viscosity has been shown to be directly proportional to the amount of beta-glucans in the sample (White et al., 1981; Smith et al., 1980; Aastrup, 1979). However, it should be noted that other substances present in the kernel contribute to the overall viscosity, such as mixtures of araboxyln, xylan,

pectin, and araban (Preece and McKenzie, 1952), thus this is not a precise analytical method.

Rotational viscometry can also be employed to determine the viscosity of a sample. In the method, the torque required to rotate a spindle at a constant speed while immersed in the sample liquid is measured. The torque is proportional to the viscous drag on the immersed spindle, and is thus proportional to the viscosity of the solution.¹

Determining beta-glucan content by fluorescence involves the use of Calcofluor to complex with the beta-glucosidic bonds, and then obtaining fluorescence spectra through the use of specialized fluorescence measurements. This is probably the most rapid and least laborious method for estimating beta-glucan content, and it has been shown to be highly correlated to the beta-glucan content of a sample as determined by other analysis of the same sample. However, the Calcofluor may also bind to other beta-glucosidic linkages such as those found in cellulose (Jensen and Aastrup, 1981).

The fourth method of beta-glucan analysis involves enzymatic procedures to hydrolyze the beta-glucans to oligosaccharides or glucose. The enzymes used are most often purified endo-beta-glucanase or partially purified bacterial beta-glucanase, along with ethanol and aqueous washings. The final glucose released is measured by a glucose oxidase test (Forrest and Wainwright, 1977; Prentice et al., 1980; Bamforth and Martin, 1981; Aman and Graham, 1987).

¹Brookfield Engineering Laboratories, Inc.

Processing

Processing refers to any treatment to which feeds or materials used to produce feeds are subjected (Harris and Crampton, 1973). Generally, feeds are processed by mechanical, thermal or chemical methods, or by microbial fermentation. Processing of feeds serves a variety of purposes, i.e., it can alter physical characteristics or particle size, prevent spoilage, improve palatability, detoxify antinutrients and poisons, or can put the feed in a form which is convenient for handling (Church, 1977). A brief review on some common processing procedures and their effect on the nutritional value of feeds follows.

Heat

Heat treatments affect both protein and carbohydrates, and the effects are increased with the presence of moisture. Proteins are denatured to some extent, which changes the protein structure enough to improve utilization, especially by young animals (Sunde, 1973). However, excessive heat in the presence of carbohydrates results in a browning process referred to as the Maillard reaction (Adrian, 1974). Because of this reaction, lysine, and perhaps some other amino acids become less available to the animal (Church, 1977). Heating fish or animal proteins appears to negatively influence growth, while controlled heat treatment of cereal grains may slightly improve protein utilization by ruminants, but shows little effect on nutritional value for monogastrics (Slinger, 1973).

Heat, especially in combination with moisture, results in gelatinization of starches (Sunde, 1973). Up to a point, this gelatinization has a favorable influence on the nutritional value of the feed. However, if extensive rupture of starch granules occurs, growth and feed efficiency are reduced (Bohstedt, 1967).

Vitamins and minerals may be slightly negatively affected by heat treatment. Thiamin, pantothenic acid, folic acid, biotin, and the fat soluble vitamins are especially sensitive to heat, light or oxygen exposure (Kohler et al., 1973). Some evidence indicates that trace minerals may become less available to the animal upon heating due to chelation of elements within the feed (Church, 1977).

Grinding and Pelleting.

Grinding of a feed acts to reduce particle size and increase surface area available for enzymatic activity. This process is widely accepted as a means to improve digestibility, but storage of ground feeds results in problems with oxidation of nutrients and increased rate of fat rancidity (Church, 1977). Some reports indicate an increase in the incidence of esophagogastric ulcers in swine fed finely ground grain (Mahan et al., 1966; Simonsson and Bjorklund, 1978; Lawrence et al., 1980). Pigs fed barley prepared in three particle sizes have shown equal gains, but feed efficiency was reduced in pigs fed the largest particle size (Simonsson, 1978).

Pelleting of a feed has several physical advantages such as dust reduction and ease of handling and storage (Cullison, 1982). Pelleting may also have some nutritional advantages by increasing the density of the diet which allows for greater consumption. Pelleting can also mask the flavor of unpalatable feeds, promoting greater consumption. The heat involved in pelleting may also destroy the activity of particular toxins (Church, 1977), but may have other effects as well.

The nutritional effect of pelleting depends on the ingredients in the diet. Generally, diets high in fiber show the greatest improvement in animal performance when pelleted, compared to their unpelleted counterparts (Krider et al., 1982).

It is not known precisely how pelleting improves feed conversion. Some studies suggest that energy digestibility is improved during the pelleting process due to a partial gelatinization of the starch or a modification of the fiber components of the feed, both of which could enhance digestibility (Krider et al., 1982). It may be that pelleting reduces bulk of diets high in fiber, enabling the animal to consume greater quantities. There is no indication that protein digestibility is improved by pelleting (Krider et al., 1982).

Regrounding of pellets does not alter the improved performance of a pelleted diet. The increased gains and higher feed efficiency of a reground corn-soy-wheat bran pelleted diet remained constant compared to the pelleted diet, and were higher than that of the original diet. It appears that poultry can consume reground, pelleted mash more easily than the original mash (Slinger, 1973).

Extrusion

Extrusion is a method of cooking in which lubricated starchy and(or) proteinaceous foods are formed and cooked in a tube through a combination of pressure, heat and mechanical shear (Smith and Ben-Gera, 1979). The forces within the tube induce gelatinization of the starches and denaturation of proteins. The dough is then expanded through exothermic reactions and is formed by openings in the die to produce shapes such as ropes, strips or tubes which are then cut to the length desired (Smith and Ben-Gera, 1979). Extrusion texturization of foods and animal feeds is widely used to produce a variety of convenience foods and snacks as well as many dry pet feeds (Chiang and Johnson, 1977).

High-temperature, short-time (HTST) extrusion cooking is the method most commonly used in modern food processing plants. This method allows temperatures to be kept reasonably low during cooking of the dough, then elevated to the desired temperatures during the last few seconds of cooking. This brief temperature increase has been shown to be equivalent in sterilizing value to lower temperatures applied for longer times (Stumbo, 1973). This process has advantages over longer cooking processes in that foods can be effectively sterilized without overcooking, discoloration or nutritional damage (Smith and Ben-Gera, 1979).

The actual extrusion equipment consists of several pieces of machinery which may vary slightly from plant to plant. Generally, the equipment includes a feeder to allow uniform and controlled feeding of the material, a preconditioner which allows processing of the food with

steam or other liquid and the actual extruder which mixes the material into a dough through the use of a screw apparatus and cooks it the required amount. The end process may also include a means of shaping and cutting the dough as desired, and dryer to cool the extrudate and reduce moisture to the desired content (Smith and Ben-Gera, 1979).

The extrusion process is actually a series of steps beginning with preconditioning. In this step, the raw ingredients are moistened and(or) heated by the addition of water or live steam. If the preconditioner is pressurized, high discharge temperatures can be achieved. Mixing of the ingredients with the moisture occurs through the action of paddles attached to rotating shafts (Harper, 1986). This preconditioning step does little to rearrange molecular structure, but simply prepares the ingredients for the extruder by reducing the amount of cooking time required in the extruder (Miller, 1985). During the actual extrusion process, continual increases in the temperature, pressure and moisture cook and expand the food to the desired bulk density (Miller, 1985).

The heating, hydration and pressure of extrusion cooking cause a reorganization of the tertiary structure of the food molecules. Larger molecules are aligned in such a way as to render them susceptible to cross-linking, forming a bulky, more porous product (Harper, 1986).

Extruded foods usually contain vegetable protein and(or) starch as a major ingredient (Harper, 1986). The effect of extrusion on these ingredients should be explored separately, but this may be difficult to accomplish since natural foods are mixtures rather than separate ingredients.

Effect of Extrusion on Protein. Defatted soybean protein is often used in extruded products to give a meat-like appearance and flavor. During the pre-processing, liquid is added to soy protein to give a dry matter of 33-45%. The mass is then heated to 80C to 90C in the preconditioner, and is then further heated during the extrusion process (Harper, 1986). This high temperature, high moisture treatment causes the protein structure to unfold and disrupts disulfide and hydrogen bonds, causing cross-linkages of the bonds within the mass (Ramsen and Clark, 1978). This forms a layered, fibrous structure which creates more flat surfaces within the soybean protein, allowing it to be rehydrated to about three times its weight, forming a meat-like product (Maurice and Stanley, 1978).

The actual nutritional compositional value of a protein changes little during the extrusion process, however the digestibility of the protein does change (Bjorck, 1983). Extrusion with mild heat treatment usually improves digestibility by deactivating protease inhibitors and other antinutritional substances. With high temperatures, protein digestibility will often decrease due to a reduced biological availability of some amino acids. The sulphur-containing amino acids are oxidized, and their sulphur groups removed under high temperatures, and lysine becomes less available in the presence of reducing sugars through the Maillard reaction (Hurrell and Carpenter, 1977). The availability of cystine and lysine appear to be the most negatively affected by extrusion processing, with the availability of arginine, histadine, aspartic acid and serine also decreased to lesser extents (Bjorck and Asp, 1983).

Effect of Extrusion on Starch. The temperature during the extrusion process is directly proportional to the amount of starch gelatinization which occurs (Chiang and Johnson, 1977). Increasing the moisture content also increases gelatinization (Bjorck and Asp, 1983). Total gelatinization of wheat flour starch can be achieved at temperatures of 110 C and 24 to 27% moisture (Bjorck and Asp, 1983). Maximum gelatinization usually occurs with high-temperatures even with low moisture contents, which makes the starch more susceptible to amylase hydrolysis (Bjorck and Asp, 1983). Heat treatment also seems to inhibit alpha-amylase inhibitors which are present in raw cereals (Granum, 1979). Therefore, extrusion can increase digestibility of starch in a product by increasing susceptibility to alpha-amylase digestion and deactivating alpha-amylase inhibitors.

The actual physical structure of the starch molecule is changed during the extrusion process. The crystalline structure is partially or completely destroyed (Charboniere et al., 1973), and thus extrusion gives the starch molecules new, functional properties which include an increase in the water soluble fraction and a concurrent decrease in molecular size (Davidson et al., 1984).

Effect of Extrusion on Other Constituents. The fat content of extruded products may be lower than in unprocessed foods. The extractable fat content of extruded pasta was lower when compared to other forms of heat treatment (Fabriani et al., 1968). Similar results have been found for wheat and maize (Delort-Laval and Mercier, 1976). This may be due to monoglycerides and free fatty acids forming complexes with

amylose during extrusion, making them less susceptible to extraction by conventional solvent methods (Mercier, 1980). The digestion and utilization of fats does not appear to be impaired with the formation of these amylose-lipid complexes (Holm et al., 1983). The decrease in fat content may also be a result of steam distillation or thermal degradation (Bjorck and Asp, 1983). With increasing temperature during extrusion, the ratio of unsaturated to saturated fatty acids appears to decrease (Bjorck and Asp, 1983). It appears that extrusion does not actually change the amount of fat in a product, although it may render it less susceptible to conventional analytical methods of extraction. The digestibility of the fat remains unchanged, although the ratio of saturated to unsaturated fats may change.

Little is written on the effect of extrusion on dietary fiber. (Fiber is defined by Bjorck and Asp, 1983 and Theander and Aman, 1983, as the non-starch polysaccharides and lignin which are resistant to enzymes.) However, it has been suggested that fiber degradation in the colon increases as particle size of the fiber decreases (Thomas and Elchazly, 1976). The mechanical treatment during extrusion could decrease particle size enough to increase fermentation in the colon (Bjorck and Asp, 1983). Some evidence suggests that extrusion may increase the water-soluble fiber components at the expense of the water-insoluble components (Asp et al., 1983).

Since some vitamins are highly susceptible to damage by such mechanisms as heat and oxidation, it seems probable that the extrusion process could be detrimental to vitamin retention and stability.

Thiamin and riboflavin stability during extrusion cooking of cereal grains has been most widely studied. The available literature indicates that thiamin is the most heat sensitive, while riboflavin remains fairly well intact during extrusion cooking (Beetner et al., 1974; Beetner et al., 1976; Harper et al., 1977; Maga and Sizer, 1978). Niacin, pyridoxin and folic acid appear to be relatively stable during extrusion cooking, although little data is available on the fate of these vitamins during extrusion cooking (Jansen, 1979).

Extrusion cooking appears to be less detrimental to vitamin C content than more conventional cooking methods (Lorenz et al., 1980). Also, the stability of vitamin C during storage has been shown to be much higher in extruded foods than in corresponding raw foods. This may be related to a reduced water activity during storage of an extruded product (Harper and Jansen, 1981).

Vitamin A and E levels actually appear to increase during the extrusion process, compared to raw material. However, it may be that extrusion simply improves the extractability of these vitamins, or that compounds formed during extrusion effect colormetric assays (Harper et al., 1977).

MATERIALS AND METHODS

Barleys

Four different barleys known to differ in their fiber content were used in this study; Hector (CI 15514), a normal covered feed barley (used as a control) and two hull-less lines, Washonupana and Franubet. There were two samples of Franubet - one harvested before snowfall (early) and one harvested from the same field after being covered by two snows and rained upon several times (late). Washonupana is a hull-less, short-awned isotype of Compana barley, (CI 5438), which has waxy (100% amylopectin) starch (Goering and Eslick 1976). Franubet is a hull-less isotype of covered Betzes (CI 6398) that has a unique starch structure which appears to be "cracked" or "fractured" upon examination with a low power microscope (Chung, 1982). All barleys were grown at the Montana Agricultural Experiment Station Farm west of the MSU campus, Bozeman, Montana in 1985.

Chemical Analysis.

The following is a list of the analyses completed on the barleys researched.

1. Moisture
2. Kjeldahl nitrogen
3. Ether extract
4. Acid detergent fiber
5. Starch
6. Ash
7. Calcium
8. Phosphorous
9. Amino acid profile
10. Relative viscosity
11. Beta-glucan (total, soluble and insoluble)

Proximate analyses and acid detergent fiber (ADF) were performed on each of the barleys according to AOAC (1980) methods. Calcium content was determined using a modified Kramer-Tisdally method (Clark-Collip, 1925), and phosphorous content was determined as described by Fiske and Subbarow (1925). Amino acid analysis of barleys and soybeans was done using a Beckman 120C automatic analyzer (Spackman, Stein and Moore, 1958). All amino acid analysis were conducted by AAA Laboratories, 6206 89th Avenue, SE, Mercer Island, Washington 98040. The viscosity of each barley was measured with the "falling ball" technique of Bendelow (1977) as described by Coon (1978). Starch was analyzed by the method of Aman and Hesselman (1984). Aman and Graham's method (1987) was followed in the determination of beta-glucans in the samples.

Physical Measurement

Percent plump was the weight of kernels on and above a 6/64 inch screen; percent thin was the weight of kernels passing through the 5.5/64 inch screen. Test weight was expressed as kg/hl. Kernel weight was determined as 30g seed per number of kernels counted x 1000, which was expressed as thousand kernel weight in grams. All tests of physical measurement were performed at the Cereal Quality Laboratory at Montana State University. Triplicate measures were performed on each sample.

Animal StudiesSwine Trial

Six diets were prepared using three of the barleys previously described; Hector, Washonupana and late Franubet. Each of the barleys was used to prepare a raw and an extruded diet (Table 1). The barleys were extruded with an Instapro^R Extruder (Triple "F" Feeds, Inc.) at Western States Industries in Choteau, Montana. Prior to extrusion, the barleys were ground and blended with cracked, undefatted soybeans in a 70/30 ratio of barley to soybeans. This was necessary to facilitate extrusion. All diets were prepared with equal amounts of minerals, vitamins and antibiotic, and met or exceeded the requirements established by NRC (1979). The extruded and raw barleys were ground through a 4.76mm hammermill screen, blended with other diet ingredients in a verticle mixer. Proximate analysis, calcium, phosphorous, starch and beta-glucan determinations were made on all diets formulated using methods previously described.

A total of 192 crossbred pigs (Duroc x Hampshire x Yorkshire) were stratified by sex, initial weight and ancestry to each diet treatment and were placed in steel wire pens in an environmentally regulated building with plastic coated wire floors. The six diet treatments were assigned in four replicate groups of eight pigs per pen, making a total of 32 pigs per diet. Feed was available ad libitum as a meal and water was provided with nipple waterers. All pigs were weighed at the start of the test and weekly for three weeks. The amount of feed consumed was recorded weekly. Individual pig average

daily gains (ADG) were computed for 0-7, 0-14 and 0-21 days. Pen group averages for average daily feed consumption (ADF) and feed to gain ratios (F/G) were calculated for the same periods. Data were analyzed by analysis of variance in a 2 x 3 x 4 factorial arrangement: two processing methods, three barleys and four replications. Main effects and all interactions were tested (SAS, 1985). Individual means of ADG and group means for ADF and F/G were the parameters used in the analyses.

Chick Trials

Chick trial 1. The four barleys as described in the swine trial plus the early Franubet, were prepared in raw and extruded diets balanced for protein and minerals (Table 2). The raw barley and extruded barley-soybean mixture were the same as fed in the swine trial. Diets were prepared as a meal and were formulated at a 20.0% protein level with supplemental vitamins and minerals to meet or exceed NRC (1984). One day-old cockerel Hubbard broiler chicks from Fors Hatchery in Puyallup, Washington were housed in a battery-type cage with thermostatically controlled compartments (35 C) with wire mesh floors. The laboratory room, located in Herrick Hall on the MSU campus, was temperature controlled (26.7 C) with continuous lighting. Chicks were number banded and allowed a 2-day adjustment period before the data collection began. After the adjustment period, chicks were stratified by weight and randomly assigned to treatment groups. A total of 21 chicks were assigned to each diet for 21 days in three replications with seven chicks per cage per treatment group. Feed and

water were provided ad libitum. Daily feed consumption was recorded and body weights were measured twice a week. Total feed consumption and feed to gain ratios were calculated. Fecal dry matter was measured on day fourteen during the course of the feeding trial.

Data were analyzed using analyses of variance in a $2 \times 4 \times 3$ factorial arrangement: two processing methods, four barleys and three replications. Main effects and all interactions were tested (SAS, 1985). Parameters tested were pen averages for treatment groups.

Chick trial 2. The late harvested Franubet barley was used to prepare 20% protein diets. Diets were prepared with ground raw and extruded barley with and without supplemental beta-glucanase, and with and without supplemental L-lysine (Table 3). Beta-glucanase, Enzeco (R) beta-glucanase, 200 units/g, was supplied by Enzyme Development Corporation, Keyport, N. J. L-lysine HCL (98% pure) was supplied by Sigma, #5626. Chick allotment, management and data collection was as described in chick trial 1. Data were analyzed in a $2 \times 2 \times 2 \times 3$ factorial arrangement: two processing methods, two levels of beta-glucanase, two levels of lysine, and three replications. Differences between means were determined using the general linear model (SAS, 1985).

Table 1. COMPOSITION OF PIG STARTER DIETS PREPARED WITH RAW AND EXTRUDED (EXT) BARLEYS, AS FED

Ingredients ^b	Raw ^a			Extruded ^a		
	WSP	HEC	LFB	WSP	HEC	LFB
	-----%					
Raw WSP	56.00					
Raw HEC		56.00				
Raw LFB			56.00			
Ext WSP				80.00		
Ext HEC					80.00	
Ext LFB						80.00
Ext soybeans	24.00	24.00	24.00			
Oat groats	9.35	9.35	9.35	9.35	9.35	9.35
Kraylets ^b	6.75	6.75	6.75	6.75	6.75	6.75
Salt	.40	.40	.40	.40	.40	.40
Dicalcium phosphate	1.55	1.55	1.55	1.55	1.55	1.55
Limestone	.80	.80	.80	.80	.80	.80
Trace mineral mix ^c	.10	.10	.10	.10	.10	.10
Vitamin mix ^d	.75	.75	.75	.75	.75	.75
Antibiotic ^e	.25	.25	.25	.25	.25	.25
Flavor supplement ^f	.05	.05	.05	.05	.05	.05

^aWSP=Washonupana, HEC=Hector, LFB=late Franubet: the barleys were extruded as a mixture of 70% ground barley and 30% cracked soybeans.

^bKraft Foods.

^cTrace mineral mix contained 20.0% zinc, 10.0% iron, 5.5% magnesium, 1.0% copper, .15% iodide, .02% selenium.

^dVitamin mix contained 500,000 IU vitamin A, 100,000 IU vitamin D, 1,500 IU vitamin E, 400 mg menadione sodium besulfite, 700 mg riboflavin, 5,000 mg niacin, 2,00 mg pantothenic acid, 4 mg vitamin B₁₂, 50,000 mg choline, and 6.5 mg biotin per .454 kg

^eAntibiotic contained 100 g chlorotetracycline, 100 g sulfa methazine and 50 g penicillin per 2.268 kg.

^fUltrasweet pignectar^R, Agriamerica, Northbrook, Ill.

Table 2. PERCENTAGE COMPOSITION OF DIETS PREPARED WITH RAW AND EXTRUDED (EXT) BARLEYS, AS FED, (CHICK TRIAL 1)

Ingredient ^b	Raw ^a				Extruded			
	WSP	HEC	EFB	LFB	WSP	HEC	EFB	LFB
Raw barley	66.50	66.50	66.50	66.50				
Ext barley					94.95	94.95	94.95	94.95
Ext soybeans	28.45	28.45	28.45	28.45				
Dical phos	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
Limestone	.60	.60	.60	.60	.60	.60	.60	.60
Supplement	.60	.60	.60	.60	.60	.60	.60	.60
Salt	.50	.50	.50	.50	.50	.50	.50	.50
DL-methionine	.30	.30	.30	.30	.30	.30	.30	.30
L-lysine ^c	.25	.25	.25	.25	.25	.25	.25	.25

^aWSP=Washonupana, HEC=Hector, EFB=early Franubet, LFB=late Franubet, EXT=extruded, FEB=full energy bean, Dical phos=dicalcium phosphate.

^bSupplement: furnishes the following (per kg supplement) 4630 USPS vitamin A acetate, 1323 ICU vitamin D₃, 3.97 USPS vitamin E, 6.6 ug vitamin B₁₂, 3.97 mg riboflavin, 6.6 mg dl-calcium pantothenate, 298 mg choline chloride, 20 mg niacin, 2.0 mg pyridoxine hydrochloride, .66 mg menadione sodium bisulfite, .66 mg thiamine mononitrate, 0.40 mg folic acid, 33 ug d-biotin, 0.06 mg sodium selenite, 30 mg manganese sulfate, 30 mg zinc oxide, 30 mg iron carbonate, 3 mg copper oxide, .9 mg potassium iodide, 66 g oxytetracycline.

^cL-lysine=L-lysine HCL

Table 3. PERCENTAGE COMPOSITION OF DIETS PREPARED WITH RAW AND EXTRUDED (EXT) BARLEYS, AS FED, (CHICK TRIAL 2)

Ingredient	Raw Franubet ^a			
	1	2	3	4
	w/o enz w/o lys	w/o enz w/ lys	w/ enz w/o lys	w/ enz w/ lys
Raw barley	64.12	64.12	64.12	64.12
Ext soybeans	30.95	30.95	30.95	30.95
Dicalcium phosphate	2.80	2.80	2.80	2.80
Limestone	.60	.60	.60	.60
Supplement ^b	.325	.325	.325	.325
Salt	.50	.50	.50	.50
D-L-methionine	.125	.125	.125	.125
Biotin	.01	.01	.01	.01
L-lysine	.32	.52	.32	.52
Beta-glucanase ^c			.05	.05
Cornstarch	.25	.05	.20	
Extruded Franubet ^a				
Ingredient	5	6	7	8
	w/o enz w/o lys	w/o enz w/ lys	w/ enz w/o lys	w/ enz w/ lys
Ext barley	95.07	95.07	95.07	95.07
Dicalcium phosphate	2.80	2.80	2.80	2.80
Limestone	.60	.60	.60	.60
Supplement	.325	.325	.325	.325
Salt	.50	.50	.50	.50
D-L-methionine	.125	.125	.125	.125
Biotin	.01	.01	.01	.01
L-lysine ^d	.32	.52	.32	.52
Beta-glucanase			.05	.05
Cornstarch	.25	.05	.20	

^aw/o enz w/o lys=without beta-glucanase, without l-lysine HCL
w/o enz, w/ lys=without beta-glucanase, with l-lysine HCL
w/ enz, w/o lys=with beta glucanase, without l-lysine HCL
w/ enz, w/ lys=with beta-glucanase, with l-lysine HCL

^bSupplement: see footnotes, table 3.

^cEnzyme=beta-glucanase: Enzeco (R) beta-glucanase, 200 units/g, Enzyme Development Corporation, Keyport, N.J.

^dL-lysine: Sigma, #5626.

RESULTS

Barleys and Diets

Table 4 shows protein, fat and fiber values of the raw barleys and of the extruded barley-soybean mixtures and extruded soybeans. Extruded soybeans were added to the raw barley diets at a level of 24% of the diet to make the raw and extruded diets similar in chemical composition. As would be expected due to the additional nutrients contributed by the soybeans, the extruded barley-soybean mixtures were higher in most of the chemical components. Extruded barley-soybean mixtures contained approximately 21.2% protein,

Table 4. PROTEIN, ETHER EXTRACT AND FIBER CONTENT OF RAW BARLEYS, EXTRUDED BARLEY-SOYBEAN MIXTURES AND EXTRUDED SOYBEANS, DRY MATTER

Ingredient ^b	Treatment	Protein	Ether extract	ADF ^a
Washonupana	Raw	17.4	2.8	3.0
	Extruded	21.3	2.3	6.3
Hector	Raw	17.0	1.8	5.8
	Extruded	22.0	2.1	7.1
Early Franubet	Raw	17.2	2.3	1.5
	Extruded	21.3	1.9	5.7
Late Franubet	Raw	16.4	2.3	1.5
	Extruded	21.7	2.5	4.9
Soybean	Extruded	33.3	20.9	8.8

^aADF = acid detergent fiber.

^bRaw barleys were whole ground kernels and extruded barleys were 70/30 mixtures of ground barley and soybeans.

Table 5. ASH, CALCIUM, PHOSPHOROUS AND STARCH CONTENT OF RAW BARLEYS, EXTRUDED BARLEY-SOYBEAN MIXTURES AND EXTRUDED SOYBEANS, DRY MATTER

Ingredient ^b	Treatment	Ash	Ca ^a	P ^a	Starch
Washonupana	Raw	2.5	.02	.47	55.4
	Extruded	3.8	.51	.47	41.8
Hector	Raw	2.2	.01	.35	51.9
	Extruded	3.2	.11	.48	38.4
Early Franubet	Raw	2.2	.02	.49	60.9
	Extruded	4.9	.15	.55	39.1
Late Franubet	Raw	2.2	.01	.52	63.8
	Extruded	3.5	.10	.58	38.9
Soybean	Extruded	6.4	.54	.70	6.9

^aCa=calcium, P=phosphorous.

^bRaw barleys were whole ground kernels and extruded barleys were 70/30 mixtures of ground barley and soybeans.

2.2% fat and 6% acid detergent fiber. Raw barleys contained approximately 17% protein, 2.3% fat and 3% acid detergent fiber.

Ash, calcium, phosphorous and starch content of the raw barleys, the extruded barley-soybean mixtures and extruded soybeans are shown in Table 5. The extruded barley-soybean mixtures contained approximately 3.9% ash, .21% calcium, .52% phosphorous and 40% starch. The raw barleys contained about 2.3% ash, .02% calcium, .46% phosphorous and 58% starch. These data are consistent between the raw and extruded mixtures, considering the added soybeans in the latter, with the exception of the starch analysis. The lower starch value for the extruded mixtures is not readily explained. Hydrolysis of the starch during extrusion may have resulted in an erroneous analytical value.

TABLE 6. AMINO ACID CONTENT OF RAW BARLEYS, EXTRUDED BARLEY-SOYBEAN MIXTURES AND EXTRUDED SOYBEAN, DRY MATTER

Ingr. ^b	Tmt. ^c	Amino Acid ^a															
		ALA	ARG	ASP	GLU	GLY	HIS	ILE	LEU	LYS	MET	PHE	PRO	SER	THR	TYR	VAL
		%															
WSP	Raw	.51	.74	.84	3.78	.44	.33	.54	1.02	.49	.21	.90	1.49	.55	.48	.51	.77
	Ext	.75	1.22	1.64	4.20	.68	.49	.80	1.44	.95	.26	1.15	1.47	.85	.70	.74	.95
HEC	Raw	.53	.78	.85	4.08	.49	.35	.58	1.10	.51	.20	1.00	1.63	.61	.50	.55	.75
	Ext	.73	1.18	1.60	4.36	.66	.49	.81	1.45	.92	.26	1.19	1.59	.84	.70	.73	.95
EFB	Raw	.55	.82	.89	4.03	.48	.37	.58	1.11	.54	.22	.99	1.71	.60	.51	.57	.75
	Ext	.78	1.25	1.79	4.34	.73	.50	.82	1.48	.98	.27	1.19	1.64	.85	.74	.76	.99
LFB	Raw	.53	.75	.55	3.64	.46	.33	.53	1.02	.51	.20	.90	1.58	.56	.47	.52	.61
	Ext	.77	1.26	1.73	4.23	.73	.49	.80	1.41	.99	.26	1.13	1.42	.88	.68	.75	.83
SB	Ext	1.24	2.25	3.42	5.28	1.20	.82	1.37	2.37	1.98	.39	1.68	1.59	1.45	1.24	1.21	1.18

^aCystine/2 and tryptophan were not determined. ALA=alanine, ARG=arginine, ASP=aspartic acid, acid, GLU=glutamic acid, GLY=glycine, HIS=histidine, ILE=isoleucine, LEU=leucine, LYS=lysine, MET=methionine, PHE=phenylalanine, PRO=proline, SER=serine, THR=threonine, TYR=tyrosine, VAL=valine.

^bIngr.=Ingredient, WSP=Washonupana, HEC=Hector, EFB=early Franubet, LFB=late Franubet, SB=soybean; Raw barleys were whole ground kernels and extruded barleys were 70/30 mixtures of ground barley and soybeans.

^cTmt.=Treatment, Ext=Extruded.

Table 6 shows the amino acid composition of the raw barleys, extruded barley-soybean mixtures and extruded soybeans. Total recovered amino acid values for the raw barleys are similar to those of the extruded barley-soybean mixture when the effects of the extruded soybeans added to the raw barleys are taken into account. For example, the calculated alanine content of the extruded 30/70 mixtures of soybeans and Washonupana, Hector, early Franubet and late Franubet barleys were .73, .74, .76, and .74%, respectively, whereas the analyzed mixtures were comparable being .75, .73, .78 and .77%, respectively.

Table 7. VISCOSITY MEASUREMENT AND BETA-GLUCAN CONTENT OF RAW BARLEYS, EXTRUDED BARLEY-SOYBEAN MIXTURES AND EXTRUDED SOYBEANS

Ingredient ^b	Treatment	Viscosity (cP)	Beta-glucan ^a		
			Total	Soluble	Insoluble
			-----%		
Washonupana	Raw	2.65	5.00	2.70	2.30
	Extruded	3.02	3.14	2.14	1.00
Hector	Raw	1.57	4.06	1.94	2.12
	Extruded	2.16	3.08	2.00	1.08
Early Franubet	Raw	1.65	4.61	2.11	2.50
	Extruded	2.87	3.12	2.01	1.11
Late Franubet	Raw	1.34	5.30	2.00	3.30
	Extruded	2.76	3.07	1.86	1.21
Soybean	Extruded	1.20	.21	.16	.05

^aPercentage dry matter.

^bRaw barleys were whole ground kernels and extruded barleys were 70/30 mixtures of ground barley and soybeans.

Viscosity measurements and beta-glucan content can be seen in Table 7. Extruded barley-soybean mixtures had an average viscosity of 2.70 centepoise units, while raw barleys averaged 1.80 centepoise units. Extruded soybeans had a viscosity of 1.20 centepoise units. Raw barleys contained a higher percentage of soluble and insoluble beta-glucans compared to the extruded barley-soybean mixtures. In all cases, extrusion caused an apparent increase in the soluble beta-glucans at the expense of the insoluble. Comparing raw barley with extruded barley-soybean mixtures, the percent of soluble beta-glucans increased from 54 to 68%, 48 to 65%, 46 to 64% and 38 to 62%, respectively, for the Washonupana, Hector, early Franubet and late Franubet barleys. There was an average increase of soluble beta-glucans in the four barleys from 46.5 to 64.8%. Extrusion did not appear to have a consistent effect on the total amount of beta-glucans. Total quantitative amounts of beta-glucans in raw and extruded barley-soybean mixtures (adjusted to 100% barley) were higher in Hector, about the same in early Franubet and lower in Washonupana and late Franubet.

Physical Measurements

Physical measurements of barley kernels can be seen in Table 8. Test weights were similar for the hull-less barleys which were 4.8 to 6.4 kg/hl heavier than Hector. Late Franubet had the highest kernel weight (42.0 mg), while Hector had the lowest (32.3 mg). A wide variation in plump and thin kernel measurements was exhibited. Late Franubet showed the highest percentage of plump kernels (68.8%), while

early Franubet and Washonupana showed the lowest percentage of plump kernels (16.8% and 17.3%, respectively). The latter barley did not differ greatly from the Hector and early Franubet in this respect. The late Franubet had more moisture since it was rained upon, to develop the greater kernel size and thus exhibited heavier kernel weight, more plump and less thin kernels than the early Franubet, which had little moisture during the growing season. The greater percent of starch in the late Franubet compared to the early Franubet (63.8 vs. 60.9%, Table 5) supports the physical measurements of these two barleys. Physical measurements of the 2-rowed Hector barleys are not typical of barleys of that type (Newman and McGuire, 1985). This barley was grown in a dry environment, thus had less chance to produce plump, heavy kernels. This is also evidenced by the low starch content of the barley (Table 5). The Washonupana barley, although grown in a different location, was also produced in an arid environment. Thus the environmental influences are expressed in the physical and chemical measurements of these barley cultivars.

Table 8. PHYSICAL MEASUREMENTS OF BARLEY KERNELS

Barley	Test weight (kg/hl)	Kernel ^a weight (mg)	Plump kernels	Thin kernels
			-----%	
Washonupana	70.0	36.5	16.8	48.1
Hector	63.6	32.3	19.3	46.2
Early Franubet	68.4	32.9	17.3	47.1
Late Franubet	68.4	42.0	68.8	9.2

^aThe values are means of duplicate analysis.

Animal StudiesChick Trials

Protein, fat, acid detergent fiber, calcium and phosphorous content of chick diets for trial 1 are presented in Table 9. Little variation was exhibited in any of these components between the diets, with the following exceptions. Diets prepared with Hector had slightly higher levels of acid detergent fiber as expected, since it is a covered barley. Average protein content of the four raw diets and four extruded diets were 19.65 and 19.68%, respectively. This indicates comparable mixing of extruded soybeans with the barleys prior to extrusion and with the raw barleys. For some unexplained reason, the extruded late Franubet diets were higher in ash, calcium and phosphorous than all other diets.

Table 9. PROXIMATE COMPOSITION OF CHICK DIETS PREPARED WITH RAW AND EXTRUDED BARLEY-SOY MIXTURES (EXT), AS FED, (CHICK TRIAL 1)

Diet ^b	Components ^a					
	PROT	EE	ADF	ASH	Ca	P
	-----%					
Raw WSP	19.7	7.2	3.7	6.7	.90	.94
Raw HEC	19.7	7.2	5.3	6.7	.93	.89
Raw EFB	20.2	7.6	4.4	7.0	.99	.97
Raw LFB	19.0	6.8	3.8	6.9	.87	.96
Ext WSP	19.7	6.1	5.6	6.8	.90	.92
Ext HEC	19.6	6.1	6.0	6.4	.90	.90
Ext EFB	19.6	7.0	4.8	6.6	.89	.96
Ext LFB	19.8	5.6	5.2	7.7	1.10	1.16

^aPROT=protein EE=ether extract ADF=acid detergent fiber Ca=calcium P=phosphorous.

^bExt=extruded WSP=Washonupana HEC=Hector EFB=early Franubet LFB=late Franubet; Raw barleys were whole ground kernels and extruded barleys were 70/30 mixtures of ground barley and soybeans.

Table 10. STARCH AND BETA-GLUCAN CONTENT OF CHICK DIETS PREPARED WITH RAW AND EXTRUDED BARLEY-SOYBEAN MIXTURES (EXT) AS FED, (CHICK TRIAL 1)

Diet ^a	Starch	Beta-glucans		
		Total	Soluble	Insoluble
		-----%		
Raw WSP	36.0	2.71	1.12	1.59
Raw HEC	33.3	2.50	.94	1.57
Raw EFB	33.8	2.49	.88	1.53
Raw LFB	33.8	2.67	.81	1.87
Ext WSP	33.9	2.51	1.25	1.23
Ext HEC	34.8	2.61	1.27	1.34
Ext EFB	35.6	2.69	1.20	1.49
Ext LFB	33.4	2.60	1.07	1.52

^aExt=extruded WSP=Washonupana HEC=Hector EFB=early Franubet LFB=late Franubet; Raw barleys were whole ground kernels and extruded barleys were 70/30 mixtures of ground barley and soybeans.

Table 10 shows starch and beta-glucan content of chick diets for chick trial 1. There was little variation in these components between the diets. However, the increased percentage of soluble beta-glucans in the extruded barley-soybean mixtures (Table 7) was evident in the diets (Table 10). The average percentage of soluble beta-glucans in the four raw barley diets was 36.1% compared to 46.1% in the diets prepared with the extruded barley-soybean mixture.

Table 11 presents the protein, fat, acid detergent fiber, ash, calcium and phosphorous content of chick diets for chick trial 2. Component levels were similar amongst all diets. Again, a good comparable mixture of the raw and extruded soybeans and extruded barley-soybean mixtures was obtained as indicated by the similar protein levels of all diets. The raw barley diets averaged 19.48% protein compared to 19.0 for the extruded barley-soybean mixture diets.

Table 11. PROXIMATE COMPOSITION OF CHICK DIETS PREPARED WITH RAW AND EXTRUDED LATE FRANUBET BARLEY-SOYBEAN MIXTURE (EXT), AS FED, (CHICK TRIAL 2)

Diet ^b	Components ^a					
	PROT	EE	ADF	ASH	Ca	P
	-----%					
Raw, w/o enz, w/o lys ^{cd}	19.7	7.0	4.3	6.8	.88	.93
Raw, w/o enz, w/ lys	20.0	7.1	3.8	6.9	.93	.94
Raw, w/ enz, w/o lys	18.9	7.0	4.1	6.8	.95	.92
Raw, w/ enz, w/ lys	19.3	7.7	3.9	6.6	.87	.93
Ext, w/o enz, w/o lys	18.9	7.1	4.5	6.6	.86	.92
Ext, w/o enz, w/ lys	19.2	7.2	4.5	6.6	.89	.95
Ext, w/ enz, w/o lys	18.6	7.0	4.6	6.6	.88	.94
Ext, w/ enz, w/ lys	19.3	7.1	4.4	6.7	.88	.94

^aPROT=protein, EE=ether extract, ADF=acid detergent fiber, Ca= calcium, P=phosphorous.

^bw/o enz, w/o lys=without beta-glucanase, without l-lysine HCL
w/o enz, w/ lys=without beta-glucanase, with l-lysine HCL
w/ enz, w/o lys=with enzyme, without l-lysine HCL
w/ enz, w/ lys=with enzyme, with l-lysine HCL
Ext=extruded.

^cEnzyme = beta-glucanase: Enzeco (R) beta-glucanase, 200 units/g, Enzyme Development Corporation, Keyport, N.J.

^dLysine: Sigma #5626.

Table 12 presents the starch and beta-glucan content of chick diets for chick trial 2. These components were similar across all diets, with the exception of the increase in percentage of soluble beta-glucans in the diets prepared with the extruded barley-soybean mixtures. The same effect of increased percentage of soluble beta-glucans in the diets prepared from the extruded barley-soybean mixtures is evidenced here as in diets prepared in chick trial 1. It is interesting to note that the addition of beta-glucanase to the diets

Table 12. STARCH AND BETA-GLUCAN CONTENT OF CHICK DIETS PREPARED WITH RAW AND EXTRUDED LATE FRANUBET BARLEY-SOYBEAN MIXTURE (EXT), AS FED, (CHICK TRIAL 2)

Diet ^a	Starch	Beta-glucan		
		Total	Soluble	Insoluble
		-----%		
Raw, w/o enz, w/o lys	32.4	2.50	1.21	1.25
Raw, w/o enz, w/ lys	28.8	2.44	1.14	1.31
Raw, w/ enz, w/o lys	35.2	2.69	1.68	1.01
Raw, w/ enz, w/ lys	30.3	2.39	1.03	1.37
Ext, w/o enz, w/o lys	32.9	2.50	1.45	1.05
Ext, w/o enz, w/ lys	32.5	2.67	1.74	.95
Ext, w/ enz, w/o lys	32.6	2.70	2.25	.46
Ext, w/ enz, w/ lys	32.2	2.67	2.46	.21

^aw/o enz, w/o lys=without beta-glucanase, without l-lysine HCL
w/o enz, w/ lys=without beta-glucanase, with l-lysine HCL
w/ enz, w/o lys=with enzyme, without l-lysine HCL
w/ enz, w/ lys=with enzyme, with l-lysine HCL
Ext=extruded; Raw barleys were whole ground kernels and extruded barleys were 70/30 mixtures of ground barley and soybeans.

also increased the percentage of soluble beta-glucans (54.6 to 63.7%) in much the same manner as did the extrusion process.

Average weight gain and feed/gain ratios for chick trial 1 are shown in Table 13. In all cases, the weight gain for chicks on extruded barley-soybean diets was significantly lower ($p < .0001$) than for those on the raw barley diets. Chicks on the raw late Franubet diet exhibited the greatest amount of gain (an average of 614 grams), while chicks on the extruded late Franubet-soybean diet showed the poorest weight gain (395 grams). Feed/gain ratios for all extruded barley-soybean diets were significantly higher ($p < .0001$) than those for the raw barley diets. Raw early Franubet exhibited the best feed/gain ratio (1.62), while extruded late Franubet-soy showed the poorest (2.37).

Table 13. COMPARISON OF RAW AND EXTRUDED BARLEY-SOYBEAN (EXT) DIETS FOR WEIGHT GAIN AND FEED/GAIN RATIO (CHICK TRIAL 1)

Diet ^a	n	Average weight gain (g) (p=) ^b	Average feed/gain ratio (p=)
Raw WSP	20	524	1.89
Ext WSP	20	404 (.0001)	2.28 (.0001)
Raw HEC	21	566	1.67
Ext HEC	20	429 (.0001)	2.12 (.0001)
Raw EFB	22	582	1.62
Ext EFB	22	413 (.0001)	2.16 (.0001)
Raw LFB	21	614	1.64
Ext LFB	22	395 (.0001)	2.37 (.0001)

^aWSP=Washonupana, HEC=Hector, EFB=early Franubet, LFB=late Franubet.

^b(P)=probability values.

Table 14. COMPARISON OF RAW AND EXTRUDED BARLEY-SOYBEAN (EXT) DIETS FOR WEIGHT GAIN AND FEED/GAIN RATIO (CHICK TRIAL 1)

Diet ^a	n	Average weight gain (g)	Average feed/gain ratio
Raw barley	84	572 ^a	1.71 ^a
Extruded barley	84	410 ^b	2.23 ^b

^{ab}Means in a column that do not have a common letter in their superscripts differ significantly (p<.0001).

Table 14 presents a comparison of raw vs extruded barley for chick trial 1. Gains for chicks on all raw diets were significantly higher ($p < .0001$) than gains for chicks on the extruded diets.

Comparisons for feed/gain ratios are also shown in Table 14. Chicks fed the raw barley diets all exhibited lower feed/gain ratios ($p < .0001$) than chicks fed extruded barley-soybean diets.

Table 15. FOURTEEN DAY DRY MATTER CONTENT AND FAT CONTENT OF CHICK FECES FROM CHICKS FED RAW AND EXTRUDED BARLEY-SOYBEAN DIETS (EXT) (CHICK TRIAL 1)

Diet ^a	n	Fecal dry matter (p=) ^b	Fecal fat (p=)
		-----%	
Raw WSP	3	28.7	6.7
Ext WSP	3	33.7 (.23)	7.4 (.34)
Raw HEC	3	29.8	5.8
Ext HEC	3	33.5 (.37)	7.2 (.0015)
Raw EFB	3	30.7	4.8
Ext EFB	3	28.2 (.54)	8.8 (.0075)
Raw LFB	3	29.4	4.5
Ext LFB	3	29.5 (.97)	8.5 (.23)

^aWSP=Washonupana, HEC=Hector, EFB=early Franubet, LFB=late Franubet.

^b(P=)=probability values.

It appeared upon visual inspection that the chicks on the extruded diets had very wet, sticky feces, much more so than the chicks on the raw diets. However, as shown in Table 15, there were no significant differences ($p > .20$) between fecal dry matter content of chicks on extruded diets compared to those on the raw diets. The fecal dry matter of chicks on the extruded diets averaged 31.2%, while the fecal dry matter of chick on the raw diets averaged 30%.

The fat content of chick feces is also shown in Table 15. In all cases, the fecal fat was higher in the chicks fed the extruded diets, however in only the Hector and early Franubet diets were these differences significant ($p < .0015$ and $.0076$, respectively). The average fecal fat of chicks fed extruded diets was 8.0%, while the average fecal fat of chicks fed the raw diets was 5.5%. The increased fat content may have made the feces from the chicks fed extruded barley-soybean diets appear to be more wet.

Table 16. COMPARISON OF RAW AND EXTRUDED LATE FRANUBET-SOYBEAN (EXT) DIETS SUPPLEMENTED WITH AND WITHOUT BETA-GLUCANASE AND LYSINE FOR WEIGHT GAIN AND FEED/GAIN RATIO, (CHICK TRIAL 2)

Diet ^a	n	Average weight gain (p=) ^b (g)	Average feed/gain ratio (p=)
1 Raw, w/o enz w/o lys	20	521	1.62
2 Ext, w/o enz w/o lys	19	349 (.0001)	2.23 (.0001)
3 Raw, w/o enz w/lys	20	516	1.60
4 Ext, w/o enz w/lys	18	307 (.0001)	2.41 (.0001)
5 Raw, w/enz w/o lys	18	569	1.53
6 Ext, w/enz w/o lys	20	506 (.0014)	1.77 (.0119)
7 Raw, w/enz w/lys	20	551	1.62
8 Ext, w/enz w/lys	15	445 (.0001)	1.91 (.0035)

^aw/o enz w/o lys=without beta-glucanase, without l-lysine HCL
w/o enz w/lys=without beta-glucanase, with l-lysine HCL
w/enz w/o lys=with enzyme, without l-lysine HCL
w/enz w/lys=with enzyme, with l-lysine HCL.

^b(P=)=probability values.

Data comparisons for chick trial 2 are shown in Table 16.

In this trial, all diets were made from late Franubet barley, which was the barley showing the widest variation in gains between raw and extruded diets in chick trial 1. In all comparisons, chicks fed extruded barley-soybean diets exhibited significantly lower ($p < .0001$) gains than chicks fed raw barleys (Table 16). The highest gain was exhibited by chicks fed raw barley with beta-glucanase (enzyme), but without supplemental lysine, but this was not significantly different from gains exhibited by chicks fed any of the raw barley diets.

The poorest gain was exhibited by the extruded diet without supplemental enzyme but with additional lysine (diet 4). This was significantly lower than gains on the other extruded diets. The second lowest gain for the extruded diets was shown by the diet without enzyme and without lysine (diet 2). The third lowest gain of the extruded barley-soy diet was exhibited by the diet with enzyme and with lysine added (diet 8). The extruded diet with beta-glucanase and without supplemental lysine (diet 6) showed gains which were not statistically different from the raw barleys without enzyme supplementation (diets 1 and 3, Table 16). The pooled means for chick trial 2 are shown in Table 17.

Table 18 presents p-values comparing the various diet components. As previously mentioned, all extruded diets resulted in a significantly lower ($p < .0001$) weight gain for chicks than the raw diets. The raw diets with and without beta-glucanase and with and without lysine resulted insignificantly higher gains for chicks than their extruded counterparts. For all diets, raw and extruded, the addition of beta-

Table 17. COMPARISON OF RAW AND EXTRUDED LATE FRANUBET-SOYBEAN (EXT) BARLEY DIETS SUPPLEMENTED WITH AND WITHOUT BETA-GLUCANASE AND LYSINE FOR WEIGHT GAIN AND FEED/GAIN RATIO, (CHICK TRIAL 2)

Diet ^a	n	Average weight gain (g)	Average feed/gain ratio
Raw barley	78	539 ^a	1.59 ^a
Extruded barley	72	402 ^b	2.08 ^b
All diets, with enzyme	73	518 ^a	1.71 ^a
All diets, without enzyme	77	423 ^b	1.97 ^b
All diets, with lysine	73	455 ^a	1.89 ^a
All diets, without lysine	77	486 ^b	1.79 ^b

^{ab}Means in a column that do not have a common letter in their superscripts differ significantly ($p=.0001-.0017$)

glucanase significantly improved weight gains while supplemental lysine decreased weight gains in extruded barley diets but had no effect on weight gain of chicks fed raw barley diets.

Swine Trial

Table 19 presents the protein, fat, acid detergent fiber, ash, calcium and phosphorous contents of pig diets. There was little variation exhibited in any of these components between the diets, with the exception that acid detergent fiber was slightly higher in the Hector barley diets and that ash, calcium and phosphorous were higher in the extruded late Franubet diet. This same difference was noted in chick diets prepared in chick trial 1.

Table 18. CONTRAST OF DIET COMPONENTS OF RAW AND EXTRUDED BARLEY-SOYBEAN (EXT) DIETS FOR GAIN (CHICK TRIAL 2)

Diet component ^a	p=
Extruded vs raw barley	.0001
Raw, w/o enz w/o lys vs ext, w/o enz w/o lys	.0001
Raw, w/o enz w/ lys vs ext, w/o enz w/ lys	.0001
Raw, w/ enz w/o lys vs ext, w/ enz w/o lys	.0014
Raw, w/ enz w/ lys vs ext, w/ enz w/ lys	.0001
All barleys, with enzyme vs without enzyme	.0001
All barleys, with lysine vs without lysine	.0017
Raw barley with enzyme vs raw barley without enzyme	.0040
Ext barley with enzyme vs ext barley without enzyme	.0001
Raw barley with lysine vs raw barley without lysine	.4133
Ext barley with lysine vs ext barley without lysine	.0002

aw/o enz w/o lys=without beta-glucanase, without l-lysine HCL
w/o enz w/lys=without beta-glucanase, with l-lysine HCL
w/enz w/o lys=with enzyme, without l-lysine HCL
w/enz w/lys=with enzyme, with l-lysine HCL.

Table 20 shows the starch and beta-glucan content of the pig diets. Again, little variation was exhibited in starch or total beta-glucans. However, as in the barley and diets fed in the chick trials, the extrusion process increased the percent of soluble beta-glucans in the diets from 46.9 to 63.1%.

Table 19. PROXIMATE COMPOSITION OF PIG DIETS PREPARED WITH RAW AND EXTRUDED (EXT) BARLEY-SOYBEANS, AS FED

Diet ^b	PROT	EE	Components ^a		Ca	P
			ADF	ASH		
			-----%			
Raw Washonupana	19.5	6.6	4.2	6.4	.77	.76
Raw Hector	20.0	7.4	5.7	6.3	.81	.68
Raw late Franubet	18.7	6.8	3.6	6.0	.73	.73
Ext Washonupana	19.7	7.0	5.4	6.3	.67	.71
Ext Hector	19.5	6.4	5.6	6.4	.79	.75
Ext late Franubet	19.6	6.2	5.4	7.5	1.01	.96

^aPROT=protein, EE=ether extract, ADF=acid detergent fiber, Ca= calcium, P=phosphorous.

^bExt=extruded.

Table 20. STARCH AND BETA-GLUCAN CONTENT OF PIG DIETS PREPARED WITH RAW AND EXTRUDED (EXT) BARLEY-SOYBEAN, AS FED

Diet ^a	Starch	Beta-glucan		
		Total	Soluble	Insoluble
		-----%		
Raw Washonupana	37.0	2.85	1.42	1.42
Raw Hector	35.3	2.72	1.30	1.43
Raw late Franubet	39.2	2.92	1.26	1.66
Ext Washonupana	35.9	2.58	1.55	1.02
Ext Hector	34.8	2.59	1.73	.85
Ext late Franubet	34.2	2.58	1.61	.97

^aExt=extruded.

Comparison of average daily gains can be seen in Table 21. Pigs fed the raw Washonupana and raw Hector diets appeared to have higher average daily gains than pigs fed extruded diets, however these differences were not statistically significant. Pigs fed the extruded

Table 21. COMPARISON OF RAW AND EXTRUDED BARLEY-SOYBEAN (EXT) DIETS FOR AVERAGE DAILY GAIN PER WEEK FOR PIG TRIALS

Diet ^a	n	Average Daily Gain		
		0-7d (p=) ^b	0-14d (p=)	0-21d (p=)
		-----g-----		
Raw WSP	32	59	181	313
Ext WSP	32	50 (.62)	145 (.19)	286 (.59)
Raw HEC	32	73	200	350
Ext HEC	32	41 (.15)	150 (.10)	295 (.31)
Raw LFB	32	64	177	300
Ext LFB	32	91 (.21)	200 (.42)	336 (.49)

^aWSP=Washonupana, HEC=Hector, LFB=late Franubet.

^b(p=)=probability values.

Franubet-soybean diet appeared to have higher gains than those on the raw Franubet diet, but again, these differences were not significant. The differences in gain between pigs fed raw and extruded barley diets became less with increasing days on test.

Table 22 presents feed/gain ratios for pigs on the raw and extruded diets. There were no significant differences in feed/gain ratios between raw and extruded barley-soybean diets. By day 14, the feed/gain ratios between extruded and raw barley diets were identical.

Table 23 presents the average feed consumption per pig on a daily basis. No significant difference was detected between consumption of the raw diet and its extruded counterpart. Amount of feed consumed per pig per day was similar across all diets.

Table 22. COMPARISON OF RAW AND EXTRUDED BARLEY-SOYBEAN (EXT) DIETS FOR FEED/GAIN RATIOS PER WEEK FOR PIG TRIALS

Diet ^a	n	Feed/Gain ratio		
		0-7d (p=) ^b	0-14d (p=)	0-21d (p=)
Raw WSP	4	5.4	2.0	1.9
Ext WSP	4	9.7 (.40)	2.2 (.35)	2.0 (.86)
Raw HEC	4	6.9	2.0	1.9
Ext HEC	4	5.9 (.84)	2.0 (.78)	1.9 (.88)
Raw LFB	4	4.1	1.9	1.9
Ext LFB	4	2.0 (.67)	1.9 (.98)	1.8 (.74)

^aWSP=Washonupana, HEC=Hector, LFB=late Franubet.

^b(p)=probability values.

Table 23. COMPARISON OF RAW AND EXTRUDED BARLEY-SOYBEAN (EXT) DIETS FOR FEED CONSUMPTION PER PIG PER DAY

Diet ^a	n	Feed Consumption		
		Week 1 (p=) ^b	Week 2 (p=)	Week 3 (p=)
Raw WSP	4	182	344	655
Ext WSP	4	188 (.78)	396 (.53)	649 (.94)
Raw HEC	4	175	383	642
Ext HEC	4	175 (1.0)	370 (.86)	597 (.61)
Raw LFB	4	175	318	603
Ext LFB	4	208 (.43)	389 (.35)	662 (.50)

^aWSP=Washonupana, HEC=Hector, LFB=late Franubet.

^b(p)=probability values.

DISCUSSION

Chemical Analysis

On a calculated basis, the extruded barley-soybean mixtures which were composed of 70% raw barley (with an average fat value of 2.3%) plus 30% extruded soybeans (with a fat value of 20.9%) should contain 7-8% fat. However, chemical analysis of fat content by the ether extract methods showed that the extruded barley-soy mixtures contained only 1.9-2.5% fat, which is only 24-31% of the fat expected (Table 4). This may be a result of amylose-fat complexes formed during extrusion which hinder the extraction of fat from the sample by normal chemical methods (Fabriani, 1968). This also supports work done by Delort-Laval and Mercier (1976) in which only 40-55% of the lipids present in raw materials could be extracted with ether after extrusion. The fat recovery in extruded wheat was 40% and of corn was only 20% of the calculated lipid content in a study done by Nierle et al. (1980). It may be monoglycerides and free fatty acids which combine with the amylose (Mercier, 1980). Other explanations of the reduced fat content are a destruction of the fat by steam distillation or thermal degradation. However, Nielsen (1976) finds that the conditions during the extrusion process do not affect lipids. It is interesting to note that in this study, the extruded Washonupana barley, which contains strictly amylopectin for starch also showed a reduced fat content. This would indicate that there may be factors other than amylose-fat complexes which are reducing the extractable fat content in

extruded product. It appears that digestibility of the lipid is not affected by these complexes, as Holm et.al (1983) found almost complete digestion of these complexes in the rat.

Davidson et al. (1984) found that starch extracted from extruded wheat samples was considerably less than that extracted from an unprocessed wheat sample, and attributed this effect to the structural modification of the starch polymer during this extrusion process. In this study, extruded barleys contained an average of 40% starch. A mixture of 70% barley (with an average starch content of 58%) plus 30% extruded soybeans (with a starch content of 6.9%) would be expected to contain 43% starch, so the extruded barleys contained only slightly less starch than expected. This may have been due to starch hydrolysis.

It is possible that the extrusion process degrades and solubilizes the beta-glucans in the barley. Asp et al. (1983) showed that extrusion may increase the water-soluble fiber components at the expense of the water-insoluble fiber components, which would lend support to this assumption. Fadel et al. (1987) presented evidence that extrusion increases the percent of soluble beta-glucans with a corresponding decrease in insoluble beta-glucans. The data in this study support this finding. Of the total beta-glucan content in the raw barleys, 47% were soluble, 65% were insoluble. Of the total beta-glucan content in the extruded barleys, 56% were soluble, 36% were insoluble. In all cases, extruded barleys were higher in soluble beta-glucans and lower in insoluble beta-glucans than their raw counterparts. The extruded barleys also exhibited higher viscosity

readings than their raw counterparts. This could possibly be related to the increase in soluble beta-glucans during the extrusion process. Smith et al. (1980) found that the viscosity of a sample is due primarily to the soluble beta-glucans present, with starch being a smaller contributing factor to the viscosity. Results of this study would agree with this work, since the extruded barleys, which contained a higher soluble beta-glucan percentage also presented a higher viscosity reading.

Chicks

Barley-based diets have been shown to reduce gains, lower feed intake, produce poor feed efficiency and cause sticky feces when fed to poultry (Laerdal, 1960; Burnett, 1968; Hesselman, 1983). Data from chick trial 1 showed that the extruded barley-soybean diets produced lower weight gains and higher feed/gain ratios than the raw barley diets. It is possible that the increase in soluble beta-glucans of the extruded diets are at least partially responsible for this reduced chick performance, since soluble beta-glucans have been shown to increase the viscosity of the intestinal fluids, thereby impairing nutrient uptake and water relationships in the gut of chicks (Prentice and Faber, 1981). It has been shown that chicks fed barley diets without supplemental beta-glucanase generally show higher fat content in the feces. It may be that dietary fats in the intestine are being sequestered by beta-glucans and thereby secreted in greater amounts. In this study, the feces of chicks fed extruded diets were, in all

cases, higher in fat than chicks on the raw diets, but only in the Hector and early Franubet diets were these differences significant. However, it should be noted that sample size was limited in this comparison. It is not known whether chicks, like rats (Holm et al., 1983) are able to completely digest amylose-lipid complexes formed during extrusion, and the increase in excreted fat may be a result of a decreased lipid-amylose complex digestion in the chick and hence, increased fecal fat excretion. Even though visual inspection indicated that the feces of the chicks fed the extruded diets were much wetter than feces from chicks fed the raw diets, the dry matter data (Table 15) showed that this was not the case. The wet appearance of the feces may have been due to the increase in fecal fat, but may also be due to unknown factors. This needs further investigation.

The results of chick trial 2 also showed a negative gain response to extruded barley-soybean diets. Even with the addition of beta-glucanase, chicks fed extruded diets did not perform as well as chicks fed raw diets without supplemental beta-glucanase. This would lend support to the assumption that the extrusion process is somehow affecting the beta-glucan molecules within the feed and exacerbating the effects of beta-glucans on the chick digestive tract. It is also possible that heat damage to all or some nutrients occurred during extrusion.

The literature indicates that lysine and perhaps some other amino acids become less available during extrusion cooking as a result of the Maillard reaction, lowering the biological value of the protein (Bjorck and Asp, 1983). The loss of available lysine has been shown to range

from 32 to 80%, with a positive correlation between the temperature of extrusion and lysine loss (Bjorck and Asp, 1983). Arginine, tryptophan, cysteine and histidine availability also appear to be negatively affected by the Maillard reaction during extrusion cooking, but not to as great an extent as lysine (Hurrell and Carpenter, 1977). In this study, lysine was added to the diets in an attempt to overcome any negative influences of the Maillard reaction on lysine availability. However, in chick trial 2, the addition of lysine appeared to be detrimental to weight gains in both the raw and extruded diets. It is not known why this occurred, but it may be due to a deficiency in other amino acids, or an unexpected excess in lysine availability in the extrusion process. Either way, an imbalance of essential amino acids may have decreased the biological value of the protein in the diets, leading to a lowered performance of the chicks.

Swine

All pig data indicated no significant difference in gains or feed consumption between the extruded and raw diets. It was hypothesized that the gelatinization of starch by the extrusion process would improve the feeding value of the barley, but in this trial, this did not appear to be the case. In older pigs (age 6 weeks to slaughter), extrusion has been shown to improve the feeding value of barley. In a study conducted at the Montana Agricultural Experiment Station, growing and finishing pigs weighing 20kg initially gained equally as well on raw and extruded diets, however, the feed

efficiency of the pigs fed extruded barley was improved by 10% over those fed raw barley (C. W. Newman, personal communication).

It may be that the three week period following weaning is not sufficient to realize any changes in weight gain or feed consumption that could be induced by an extruded diet. It was apparent that extrusion did not improve or decrease the feed value of these barleys for pigs weaned at three weeks of age.

CONCLUSIONS

The results of the data gathered in this study indicate that the extrusion process does have an effect on some of the nutritional components of a barley-based diet. Extrusion appears to increase the soluble beta-glucans at the expense of the insoluble beta-glucans, and also appears to have a negative effect on the extractability of fat from a sample, perhaps due to the formation of amylose-lipid complexes.

Extrusion of a barley-based diet was shown to be detrimental to the chick digestive system when compared to raw barley-based diets. Chicks fed extruded-barley diets exhibited significantly lower weight gains and significantly higher feed/gain ratios than chicks fed raw barley-based diets.

Extrusion processing had no apparent effect on the nutritional quality of barley-based diets for young pigs. Average daily gain, feed/gain ratios and feed consumption were not significantly different between pigs fed extruded diets and those fed raw diets.

This study introduced many areas which need further investigation. Young pigs do not exhibit any differences between raw and extruded diets, while broiler chicks appear to be highly sensitive to changes caused by extrusion. The effect of extrusion processing on the nutrition of other species need to be further explored.

The effect of extrusion processing on beta-glucans also needs further investigation. While there is an apparent increase in beta-glucan solubility with extrusion, other unknown factors may be involved which contribute to this apparent increased solubility. It is also

assumed that it is the soluble beta-glucans which cause problems for chicks in barley-based diets. The effects of insoluble beta-glucans are unknown, but are assumed to be negligible. It may be that insoluble beta-glucans do have an effect on the digestive system, and also contribute to poor performance of chicks fed barley-based diets. This is another area which is wide open to investigation.

This study of barley, extrusion, chicks and pigs left many questions unanswered. It did, however, contribute a little more to our knowledge of nutrition and it's importance to animal life. In order to completely understand the results of this study, it is evident that the effects of extrusion on the structural composition of beta-glucans be defined.

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