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

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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ABSTRACT

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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 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 hardiness, 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 (Miflin 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 cellotriosyl and cellotetraosyl 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; Hessleman, 1983; Hesselman and Åman, 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, solibulized 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 degredation 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 araboxylan, 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; Åman and Graham, 1987).

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[1]Brookfield 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 esophagogastic 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).

Regrinding 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 Åman, 1983, as the non-starch polysaccharides and lignin which are resistant to enzymes.) However, it has been suggested that fiber degredation 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 Agricultrual 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 Åman and Hesselman (1984). Åman 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 Studies

Swine 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 ancestory 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 x 4 x 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 x 2 x 2 x 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

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

[b]Kraft Foods.

[c]Trace mineral mix contained 20.0% zinc, 10.0% iron, 5.5% magnesium, 1.0% copper, .15% iodide, .02% selenium.

[d]Vitamin 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 B_{12}, 50,000 mg choline, and 6.5 mg biotin per .454 kg

[e]Antibiotic contained 100 g chlorotetracycline, 100 g sulfa methazine and 50 g penicillin per 2.268 kg.

[f]Ultrasweet pignectar[R], Agriamerica, Northbrook, Ill.