EFFECTS OF HARD AND SOFT RED WINTER WHEAT AND WHEAT PRODUCTS ON THE PELLETING PROCESS

by

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INTRODUCTION

The manufacture of pellet mills began in Europe in the early 1900's. Since that time the production of a firm, durable pellet with a minimum of fines or crumbles has been a major problem. Customer preference demands a pellet that is durable over a pellet that falls apart.

Pelleting feeds provides several advantages over mash feed. These include: reduced dustiness, improved handling characteristics, decreased segregation, and increased bulk density. Increasing energy and equipment costs, however, are making it more difficult to justify the pelleting of formula feeds.

Pelleting aids are used by almost all feed manufacturers to produce durable pellets. The use of pelleting aids not only assists in producing a more durable pellet but sometimes improves production efficiency. Thus, by incorporating pelleting aids into pelleted feed rations, the energy requirements to pellet feeds and the wear on equipment may be held constant or even reduced.

There are two types of pelleting aids: binders and lubricants. Binders increase pellet durability. Lubricants reduce wear and friction in the pellet mill, ultimately increasing production capacity and decreasing energy requirements. Some pelleting aids are used as both binders and lubricants.

It is commonly accepted that most popular binders do not contribute significantly to the nutrient value of the feed and, in many cases, they dilute nutrient density and force reformulation. There are several ingredients available, however, that are both nutritionally sound and should, theoretically, be good pellet binders.

This research project was initiated to obtain information on the effect of various pelleting aids and ingredients on pellet quality, production rates, and energy requirements. The pelleting aids and ingredients examined were: hard red winter wheat (HRW), soft red winter wheat (SRW), second clears flour (SCF), and B-grade starch (BGS). SCF and BGS were compared to pelleting aids of known quality: sodium bentonite and calcium lignosulfonate.

LITERATURE REVIEW

Pelleting can be defined as an extrusion type thermo-plastic molding operation where the finely divided particles of a feed ration are formed into a compact, easily handled pellet (R. H. Leaver, personal communication). It is thermo-plastic because the proteins and sugars of feed ingredients become plastic when heated and diluted with moisture. Forming occurs when the heated and moistened feed is held in the die for a short period of time and then extruded. Pressure for both the forming and extrusion comes from the rolls which trap feed on the face of the die and force it through the die holes.

The advantages of pelleting are:

I. Better utilization of ingredients by animals and poultry due to the combination of moisture, heat and pressure which produce a degree of starch gelatinization

II. Prevention of selected feeding

III. Prevention of ingredient segregation in handling and transit

IV. Increased bulk density

V. Better material handling characteristics

VI. Reduced feeding losses.

The pelleting of formula feeds involves many variables but percent pellet fines, pellet durability, pellet production rate, and energy consumption are of major concern to the feed industry. The following section will include a discussion of the major pelleting variables and how they are related to the above mentioned concerns.

Percent pellet fines, pellet durability, pellet production rate, and energy consumption are all affected by at least one of the following pelleting variables: feed composition, feed texture, mash uniformity, ingredient particle size, steam temperature, steam pressure, steaming rate, ambient conditions, operator experience, pelleting pressure in the die, pelleting temperatures, feed time in die, die thickness and design, die condition, and pellet size (Wornick, 1959).

Small changes in formulation can significantly increase pelleting capacity. Corn, sorghum, oats, and barley are the grains most commonly used in complete feed rations. Of these four grains, corn is the easiest to pellet and has the highest production capacity. Sorghum yields the poorest pelleting capacity (Wake, 1959).

Protein, fiber, and fat content are important when considering the pelletability of feed formulations (AFMA, 1982; MacBain, 1966; Wake, 1959). High pellet production rates can be expected when the ingredients used in the ration contain high levels of protein. Improved pellet quality was observed when natural protein was subjected to heat and pressure causing it to plasticize (AFMA, 1982 and MacBain, 1966).

Ingredients with low bulk densities result in reduced pellet production rates with high fiber feed ingredients usually associated with low bulk densities. Fiber, however, acts as a natural pellet binder to produce a quality pellet (AFMA, 1982 and MacBain, 1966), thus, in a ration containing a high percentage of fiber, a low production rate and high quality pellets can be expected.

With ingredients high in fat or when fat is added to a formula, electrical energy required to pellet and wear on the die and roller assembly are reduced. Excess fat in a diet (greater than 2%), may seriously affect pellet quality (AFMA, 1982). Fat should be sprayed on hot pellets in diets that require high levels of fat (MacBain, 1966). Research has shown that fat can be added to pellets already formed without softening the pellet (Kathman, 1959).

Tough, durable pellets are difficult to produce when high starch ingredients are used in a formula and high temperature and moisture levels must be used to gelatinize the starch (AFMA, 1982). Gelatinization in feed pelleting has been described as "the complete rupturing of the starch granule brought about by a combination of moisture, heat, and pressure, and in some instances mechanical shear" (Smith, 1959).

Pellet durability was shown to increase when starch is gelatinized (Smith, 1959). Fines were reduced from 8.43% at 20% gelatinization to 4.70% at 28% gelatinization. These results were obtained at conditioning temperatures of 92 and 130 F. Additional study results were inconsistent in that pellet durabilities decreased and percent fines increased at higher conditioning temperatures (>160 F).

The effect of particle size on pellet durability gives conflicting results. More grain surface is exposed to steam during conditioning as particle size is reduced (Smith, 1962). Mash density is increased allowing for greater compaction in the pellet mill die. Fracture points due to large particles or long fiber strands in the pellet are reduced when particle size is decreased and liquids are absorbed more uniformly.

Smith (1962) reported a slight increase in pellet durability with corn through a 4/64 in. vs. an 8/64 in. screen. Improved pelletability and increased pellet mill capacity were also observed. Other advantages observed, due to a finer grind, were increased roll and die life due to less grinding of material at the point of roll and die contact, improved conditioner efficiency, and smoother and steadier pellet mill operation.

Baker, et al (1961) reported a major disadvantage in reducing mash particle size is that grinding capacities are reduced by more than 50% as hammermill screen sizes are decreased from 16/64 in. to 6/64 in. on corn, oats, and barley. Other cited disadvantages are: shorter grinding equipment life, increased operating maintenance, shortage of special bin space, bridging problems in bins and spouting systems due to increased product density and the need for greater dust control measures.

Stroup (1959) reported, "the most practical fineness of grind is when the mash will pass through a 7 mesh wire". However, each manufacturer must determine the appropriate particle size for his particular operation.

The above discussion indicates that better pellets and higher production rates will result when particle size is reduced. In contrast, research has shown no significant differences in pellet durability resulted by finer grinding (Young, et al, 1962a). Stevens (1962) also reported that there were no significant effects on pellet durability due to particle size reduction (8/64 in. vs. a 16/64 in. screen).

The use of steam in conditioning the mash for pelleting yields an increased production rate and harder, more durable pellets (Skoch et al, 1981). Production rates were increased by 250 and 275% when mash temperature was increased to 65 and 78 C, respectively, over dry pelleting. Pellet durability was increased from 79.1 at 27 C to 93.5 at 65 C, and 96.5 at 80 C. Bartikoski (1962) and Young and Pfost (1962b) also reported that pellet durability and pelleting efficiency can be substantially improved by the proper steam conditioning of mash. Production rates have been shown to be directly related to the amount of steam added.

Steam provides lubrication of the pellet die, thus, reducing wear on the die and roller assembly. It brings to the surface of pellet mash particles the natural oils which are common to most grains. This means greater pelleting capacity and die lubrication. The use of as dry of steam as possible will give better results in finished pellets (Wake, 1959). By the use of "high heat" pelleting, the pellets, when cooled, will emerge from the cooler with a tougher, more durable finish, which will resist disintegration in handling.

Instantaneous pelleting pressures in the die are not well known. The pressures are believed to be from 1000 to 40,000 p.s.i. (Wornick, 1959). Production rates, formula composition, fat levels, and many other factors will affect these pressures.

There has been very little research on the temperature of pellets inside the die. Estimates of these temperatures are from 350 F to 1000 F (Wornick, 1959). The extreme pellet temperatures are theorized to occur instantaneously and affect only the outer surface of the pellets while they are in the die.

Many factors affect pellet temperatures. Some of these are: mash composition, fat levels, die size, temperature of steam, production rates, moisture level of mash, particle size, bulk density, roll settings and hardness of the pellet being produced.

Production rate, number of holes in the die and die thickness are factors governing the time that feed is in a pellet die (Wornick, 1959). Increasing production rate decreases residence time. An increase in residence time will result from the use of a thicker die or a die with more holes if production rate is held constant. The time in the die has been calculated to be several seconds by use of the following formula (Wornick, 1959):

$$t = \frac{.004 \times N \times G}{W}$$

t = number of seconds required for a particle of feed to pass through the pellet mill die

.004 = a constant

N = number of holes in the die

G = weight in grams of one feed plug having a length equal to die thickness

W = pellet production rate in tons/hour.

The selection of the right die is one of the most important factors in producing quality pellets. The die selected is usually the die that will maintain the greatest production in the majority of formulations. In pelleting concentrates and supplements, a thin die (1 3/4" thickness) usually does a satisfactory job and maintains peak production. Using the same die, excessive fines will be produced when pelleting a complete ration (Wake, 1959). The number of holes in a die, entry taper of the hole, and thickness of the die are the three variables important in the design and selection of a die (Stroup, 1959).

Increased production rates are observed when a wide die is used because of the larger number of holes in the die. The term wide die" is defined as a die having a width of 6 in. as compared to a narrow die having a width of 5 in. (Stroup, 1959). The wide die gives an increased die surface and the mash is spread into a thinner layer, permitting greater conditioning and increased production rate.

When greater compression is required, an entry taper for die holes is needed. There are fewer die holes in a taper entry die. Production rates will be decreased and pellet durability will increase when using this type of die. This die design is only used where there is a need for extreme compaction and is impractical for general use.

Pfost (1965) showed die thickness can be used to increase pellet durability, however, a thicker die generally requires more horsepower per unit of production than a thinner die. When oil content in feed is at a 2% level or above, the production rate was not decreased by going from a 2" to a 2 1/2" die (on 3/16" pellets). If this same die were used to pellet a ration with no added oil, production would be severely reduced (Nesseth, 1962). Following are some of the advantages and disadvantages of using both thin and thick dies (J.L. Parker, personal communication).

THIN DIE

Advantages:

I. Higher capacity

II. Less chance of plugging

III. Use of higher moisture ranges

IV. Obtain higher conditioning temperatures

V. Adaptable for wider formulation variables

VI. Reduces die and roll cost

VII. Reduces stresses on equipment thus lowering maintenance

VIII. Decreases power requirements resulting in lower costs

Disadvantages:

I. Increase steam requirements

II. Higher moisture level may necessitate increasing air velocity in cooling system

III. May require more management control for quality expectations

IV. Pellet appearance may be dull

V. Pellet quality depends to a greater extent on the operator

VI. Pellet density may decrease slightly

THICK DIE

Advantages:

I. Less management involvement to maintain constant pellet quality

II. Pellet quality less dependent on operator skill

III. Reduces drying problems as related to cooling

Disadvantages:

I. Decreases productivity

II. More sensitive to "plug up"

III. Higher power costs per ton

IV. Die and roll costs increased

V. Lower temperature achieved

VI. Less moisture may be added

VII. Temperature increase due to higher friction

VIII. More apt to roll over holes on die.

Pelleting Aids:

Almost all feed manufacturers use pelleting aids to produce more durable pellets. An ideal pelleting aid would be one that has definite adhesive properties that will bind the feed particles together, improves the durability of pellets, reduces fines, improves pellet mill efficiency, adds nutritional value to the formula and is economical to use (Heideman, 1962).

There are two types of pelleting aids: binders and lubricants. Binders increase pellet durability while lubricants reduce wear and friction in the pellet mill, ultimately increasing production capacity and decreasing energy requirements.

Many types of pelleting aids are being used and tested in the feed industry. Following are some of the types of materials used as pelleting aids and information as to their effect on pellet durability, production rates, and other factors.

Bentonites were among the first pellet binders to be used by the feed industry. Bentonite is chiefly montmorillonite which is defined as, "a soft, clay like mineral, white, grayish, or pale red, blue". The two most commonly used types of bentonite are calcium bentonite containing up to 3% calcium and sodium bentonite containing up to 3% sodium (Kurnick et al, 1960). Table 1 defines a partial chemical analysis of bentonite.

TABLE 1. PARTIAL CHEMICAL ANALYSIS OF BENTONITE[1]

Constituent	%
Silica (SiO_2)	64.32
Alumina (Al_2O_3)	20.74
Ferric Oxide (Fe_2O_3)	3.03
Ferrous Oxide (FeO)	.46
Phosphoric Acid (P_2O_5)	.01
Lime (CaO)	.52
Magnesia (MgO)	2.30
Soda (Na_2O)	2.59
Potash (K_2O)	.39
Sulfur (SO_3)	.35

[1] Stevens, 1962

Moisture and heat must be added to the feed for bentonites to be used to their potential. Sodium bentonite has a greater water-binding capacity than does calcium bentonite. Sodium bentonite usually produces a harder pellet than calcium bentonite (Olentine, 1980).

A low steam pressure is recommended when using bentonites. This results in more condensation of steam into moisture in the conditioning chamber. A thinner die is also recommended when using bentonites. This permits the use of more steam in the conditioning chamber without choking the mill (Olentine, 1980). The amount of bentonite used in a ration varies from 1-5% (Heideman, 1962). When using bentonite at higher levels, moisture addition must also be increased in order to assure adequate hydration.

Calcium lignosulfonate has excellent adhesive properties, improves the durability of pellets and improves the production of the pellet mill while reducing the amount of fines. Some studies have shown that calcium lignosulfonate has some nutritional quality (Heideman, 1962).

Calcium lignosulfonate is a by-product of the sulfite pulping of wood. The binding qualities of lignosulfonate binders are due to the actual lignin sulfonate and carbohydrate components extracted during the pulping process. Table 2 shows a partial chemical analysis of "Lignin Extract".

Pfost (1965) reported a reduction in power requirements when using lignin as a pelleting aid. The greatest reduction of power requirements was obtained in going from 0 to 1%. Pellet durability was also increased. The increase was more significant between 0 and 1% than between 1 and 2%.

TABLE 2. PARTIAL CHEMICAL ANALYSIS OF "LIGNIN EXTRACT"[1]

Constituent	%, Dry Basis
Calcium lignosulfonate	60
Reducing Sugars:	
Hexoses	15
Pentoses	7
Hemicelluloses	14
Inorganics	4

[1]Stevens, 1962

Lignin sulfonate is reported to yield good results over a wide range of operating conditions. Good results are attained when conditioning temperatures are as low as 120 F (Olentine, 1980). Lignin sulfonate should not exceed 4% of the finished feed (AAFCO, 1981).

Nutri-binder® is a product of Progressive Grain Processing Corp., Lubbock, Texas. It is a patented product made of 100% milo, thus, can replace grain in the ration pound for pound. It is non-hygroscopic and does not absorb moisture from the air. It's recommended usage is 2 to 2.5% (NFIA, 1981).

Pre-gelatinized corn starch and grain powders are cereal by-products. They will improve durability and reduce fines due to their adhesive qualities. These by-products add as much nutritional value as the grain they replace and have no detrimental effect on vitamins and other feed additives (Heideman, 1962). The recommended usage levels are from 1 to 3%. However, this type of product is often quite expensive to use.

Cellulose gums are sometimes used in pelleting as binders and lubricants. Sufficient moisture must be added during conditioning to assure proper hydration. Cellulose gums will improve pellet durability and decrease motor load by reducing friction. A .05 to .10% usage level is recommended (Olentine, 1980).

Pelleting aids within the limits of economics and performance are a useful tool in improving pellet quality. There are many types of pelleting aids available. No pelleting aid will be the best under all conditions.

LITERATURE CITED

AFMA. 1982. Feed ingredient characteristics. In Pellet Mill Operations Manual. A.F.M.A., Arlington, Virginia., p. 17.

Baker, R.J. and E.P. Farrell. 1961. Factors that affect the granulation and capacity in grinding corn, oats and sorghum grain with a hammermill. Feedstuffs 33:13 p. 26.

Bartikoski, R. 1962. The effect of steam on pellet durability. In Cost Reductions Through In-Plant Production Controls. Proceedings of 1962 Feed Production School. p. 42.

Hastings, W.H. 1960. How operating adjustments affect pelleting. Feed Age. 10:4 p. 45.

Heideman, A.G. 1962. The effect of binding agents on pellet durability. In Cost Reductions Through In-Plant Production Controls. Proceedings of 1962 Feed Production School. p. 51.

Kathman, A.J. 1959. Fat handling. In Pelleting and Related Subjects. Proceedings of 1959 Feed Production School. p. 122.

Kurnick, A.A. and R.L. Reid. 1960. Poultry nutrition studies with bentonite. Feedstuffs 32:52 p. 18.

MacBain, R. 1966. Pelleting animal feed. American Feed Manufacturers Association. Arlington, Virginia.

Nesseth, K.A. 1962. The importance of die selection in increasing pellet durability. In Cost Reductions Through In-Plant Production Controls. Proceedings of 1962 Feed Production School. p. 53.

NFIA. 1981. In Specialty Ingredients Handbook. National Feed Ingredient Association. Sept. 1981. p. 25.

Olentine, C.G., Jr. 1980. Pelleting aids. Feed Management. 31:11 p. 8.

Pfost, H.B. 1965. The effect of lignin binders, die thickness, and temperature on the pelleting process. Feedstuffs 36:20.

Skoch, E.R, K.C. Behnke, C.W. Deyoe, and S.F. Binder. 1981. The effect of steam-conditioning rate on the pelleting process. Anim. Feed Sci-Technol., 6:83-90.

Smith, G.M. Jr. 1962. The effect of particle size. In Cost Reductions Through In-Plant Production Controls. Proceedings of 1962 Feed Production School. p. 47.

Smith, O.B. 1959. Factors in conditioning pellet mash. In Pelleting and Related Subjects. Proceedings of 1959 Feed Production School. p. 40.

Stevens, C. Jr. 1962. Effect of binders, steam and particle size on pelleting. In Cost Reductions Through In-Plant Production Controls. Proceedings of 1962 Feed Production School. p. 40.

Stroup, R.L. 1959. Pelleting dairy feeds. In Pelleting and Related Subjects. Proceedings of 1959 Feed Production School. p. 18.

Wake, P.C. 1959. Complete ration pellets for poultry and swine. In Pelleting and Related Subjects. Proceedings of 1959 Feed Production School. p. 14.

Wornick, R.C. 1959. Feed pelleting and it's effect on micro-ingredients. In Pelleting and Related Subjects. Proceedings of 1959 Feed Production School. p. 180.

Young, L.R., H.B. Pfost, and A.M. Feyerherm. 1962a. Mechanical durability of pellets. Paper No. 62301. American Society of Agricultural Engineers.

Young, L.R. and H.B. Pfost. 1962b. The effect of colloidal binders and other factors on pelleting. Feedstuffs 34:32.

EFFECT OF HARD RED WINTER WHEAT (HRW) ON THE PELLETING PROCESS

(Study 1)

INTRODUCTION

These studies were conducted to obtain information on the effect of various pelleting aids and ingredients on percentage of fines returned to the pellet mill, pellet durability, production rate and energy consumption. The pelleting aids and ingredients examined were: 1) hard red winter wheat (HRW), 2) soft red winter wheat (SRW), 3) second clears flour (SCF), 4) B-grade starch (BGS), 5) sodium bentonite and 6) calcium lignosulfonate.

The research was divided in three studies. Study 1 used HRW as a pelleting aid while SRW was similarly used in Study 2. A third study examined SCF and BGS as pelleting aids and compared them with sodium bentonite and calcium lignosulfonate.

There was no attempt made to evaluate the economic aspects of the results due to the large variability in ingredient price and availability depending upon geographic location. There was also no attempt to statistically analyze the results between corn and sorghum grain based diets because of the time span between pellet trials, ingredient variations, and the design of this research. However, the trends between corn and sorghum grain diets will be discussed.

EXPERIMENTAL PROCEDURE

This study was designed to evaluate hard red winter wheat (HRW) as a pelleting aid with either corn or sorghum grain as the cereal portion of the diet. The HRW replaced either corn or sorghum on a pound for pound basis at 0, 5, 10, and 20% levels.

The KSU Pilot Feed Mill was used for this study. The grain and HRW portions of the swine rations (table 3), were ground separately through a 3.2 mm screen with a 30 horsepower, Jacobson hammermill[1]. The ground grain was mixed with the remaining ingredients in a 454 kg. capacity horizontal double ribbon mixer. Pelleting was done with a 25 horsepower Master Model California pellet mill[2] equipped with either a 50.8 mm or 38.1 mm thick die with a 4.8 mm diameter bore. Prior to each series of runs, the die was taken to operating conditions by pelleting a warm-up feed. During each pelleting run, the pellet mill was brought to a stable operating condition (70 C and 85% motor load) and the flow of the pellets was diverted from a vertical pellet cooler to a double pass horizontal dryer-cooler for data collection. The pellets were cooled for an average of 8.5 minutes using ambient air. Fines were separated from whole pellets by a scalper and were not returned to the pellet mill but were collected separately. Pellets and fines were weighed separately and percentages of fines and production rates were determined. Run time was the lapsed time from when the pellet flow was diverted to the cooler until motor load decreased to <50% at the end of the run.

Voltage and amperage were recorded on a recording volt-amp meter. Temperatures were recorded for the mash before and after conditioning and for pellets on a sample collected immediately after the pellet die.

[1]Jacobson Machine Works, Minneapolis, Minnesota.

[2]California Pellet Mill Co., San Francisco, California.

TABLE 3. SWINE DIETS USED FOR PELLETING STUDY 1 WITH HRW AS PELLETING AID.

Ingredient	International Ref. No.	Diet (% HRW) 0	5	10	20
		- - - - - - (%)	- - - - - -		
Ground corn or sorghum grain	4-26-023 4-20-893	76.1	71.1	66.1	56.1
HRW	4-05-268	0	5	10	20
Soybean Meal (44%)	5-20-637	20.3	20.3	20.3	20.3
Dicalcium Phosphate	6-28-335	1.2	1.2	1.2	1.2
Limestone	6-02-632	1.3	1.3	1.3	1.3
Salt	6-04-152	.5	.5	.5	.5
Trace Mineral Premix	---	.1	.1	.1	.1
Vitamin Premix[1]	---	.5	.5	.5	.5

[1]Provides per Kg of diet, 4405 USP Units Vitamin A; 330 USP Units Vitamin D3; 22 International Units Vitamin E; 5 mg Riboflavin; 1.7 mg Menadione; 13.2 mg d-Pantothenic Acid; 27.5 mg Niacin; 508 mg Choline Chloride and .02 mg Vitamin B_{12}.

Formulas for calculating the Pellet Durability Index (PDI), percent fines, production rate and energy consumption are shown in table 4. A power factor of .85 and a voltage of 420 v were used in calculating energy consumption.

Samples for various analytical procedures and physical measurements were taken from four locations: 1) one sample from a belt conveyor prior to the conditioning chamber (for temperature and moisture), 2) one sample after the conditioning chamber (moisture), 3) six samples immediately after pelleting (one for moisture, one for temperature, and four for pellet durability), 4) one sample at sack-off (moisture). Moistures were determined using an air oven procedure (130 C for 2 hours) (AOAC, 1970). Samples for PDI were cooled and durability was determined using 500 grams of cooled pellets and a No. 5 screen size[1] by the procedure described by Pfost (1976). An average for the four samples was determined and reported.

The experimental design used for Study 1 was a randomized complete block design with four treatments in three blocks for both corn and sorghum grain diets. Results were statistically analyzed using analysis of variance (ANOVA) protected by Duncan's Multiple Range Test (SAS, 1979). Linear regression equations were generated for predicting PDI as a function of percent HRW (SAS, 1979). The data were checked for curvature using polynomial regression (SAS, 1979).

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[1]American Society for Testing and Materials, ASTM E 11-61, Specifications for Wirecloth Sieves for Testing Purposes.

TABLE 4. FORMULAS FOR CALCULATING PELLET DURABILITY INDEX (PDI), PERCENT FINES, PRODUCTION RATE AND ENERGY CONSUMPTION.

$$\text{PDI} = \frac{\text{weight of pellets after tumbling}}{\text{weight of pellets before tumbling}} \times 100$$

$$\text{Percent Fines} = \frac{\text{weight of pellets fines}}{\text{weight of fines + weight of pellets}} \times 100$$

$$\text{Production Rate} = \frac{\text{weight of fines + weight of pellets (kg)}}{\text{run time (hr)}}$$

$$\text{Energy Consumption} = \frac{\text{Amps} \times \text{Volts} \times \text{P.F.} \times \sqrt{3}}{\text{Tons/Hr} \times 1000}$$

P.F. = Power Factor = .85
Volts = 420

RESULTS AND DISCUSSION

The swine diet was selected for use in these pelleting trials because it is representative yet would likely respond to the use of a pelleting aid. Results of these trials, using this formula, would apply to pelleting procedures for other formulas; but the magnitude of the response may be higher or lower depending upon the ingredients. Operating conditions used were 70 C and 85% motor load. These conditions were just below the choke point and therefore, were used to the point of highest production efficiency.

Fines Return:

Fines return has been shown to be highly correlated to pellet quality (K.C. Behnke, unpublished data). The percent fines returned to the pellet mill for Study 1 are shown in table 5. When the corn based ration was pelleted with the thick die, no difference ($P > .05$) was shown between 0, 5, and 10% levels of HRW. At 20% HRW, fines return was reduced ($P < .05$) from 6.03% to 3.70%. When the sorghum based ration was pelleted through the thick die, fines return was reduced ($P < .05$) with each increased level of HRW.

Fines were reduced ($P < .05$) at 10 and 20% levels of HRW when the corn based ration was pelleted with the thin die. No differences ($P > .05$) were shown between 0 and 5% levels of HRW, however, with sorghum grain as the cereal portion of the diet, fines were reduced ($P < .05$) with each increased level of HRW.

HRW appeared to be more effective in reducing fines at lower levels in sorghum grain based rations than in corn based rations. However,

TABLE 5. EFFECT OF LEVEL OF HRW, DIE THICKNESS, AND CEREAL TYPE ON FINES RETURN[1]

Percent HRW	Die Thickness: 50.8 mm[2]		Die Thickness: 38.1 mm[2]	
	Corn	Sorghum	Corn	Sorghum
	(%)			
0	6.03[a]	5.53[a]	13.47[a]	17.43[a]
5	5.47[a]	4 87[b]	12.57[a]	15.37[b]
10	5.00[a]	4.23[c]	11.10[b]	12.67[c]
20	3 70[b]	3.50[d]	9.33[c]	9.30[d]

[1]Values are means of 3 replications.

[2]Thick die = 4.8 x 50.8 mm, Thin die = 4.8 x 38.1 mm.

[abcd]Column means with same superscript are not significantly different ($P < .05$).

when the thin die was used, the amount of fines produced at the lower levels of HRW tended to be higher for sorghum based rations than for corn based rations. Fines return appeared to be slightly lower for sorghum based rations when the thick die was used. At 20% HRW, the amount of fines produced were essentially the same for corn and sorghum rations pelleted with either die.

Fines were reduced for each diet by more than 50% when the rations were pelleted using a thick die. This observation is consistent with research by Pfost (1965), who showed that a thicker die can be used to decrease fines.

Pellet Durability:

Table 6 shows the PDI values for Study 1. In general, durability increased as the level of HRW increased from 0 to 20% for both cereal based rations pelleted on either die.

The corn based ration pelleted with the thick die showed no difference in PDI ($P > .05$) between 5 and 10% levels of HRW. However, all three levels (5, 10, and 20%) gave a higher ($P < .05$) PDI than did the control (0% HRW). The sorghum based ration pelleted with the thick die showed essentially the same results as the corn based ration. Durability was increased ($P < .05$) with each increase in level of HRW.

PDI's for corn and sorghum grain based rations pelleted through the thin die were considerably lower than those for the same diets pelleted with the thick die. The results, however, were consistent in that the PDI increased ($P < .05$) as the level of HRW increased. The corn based rations showed a significant increase in PDI ($P < .05$) with each increase in the level of HRW. The sorghum based ration showed increases in PDI

TABLE 6. EFFECT OF LEVEL OF HRW, DIE THICKNESS, AND CEREAL TYPE ON PELLET DURABILITY INDEX[1]

Percent HRW	Die Thickness: 50.8 mm[2] Corn	Die Thickness: 50.8 mm[2] Sorghum	Die Thickness: 38.1 mm[2] Corn	Die Thickness: 38.1 mm[2] Sorghum
	- - - - - - - Pellet Durability Index (%) - - - - - - -			
0	94.3[a]	93.4[a]	74.5[a]	76.5[a]
5	95.2[b]	94.3[b]	77.0[b]	76.8[a]
10	95.3[b]	95.2[c]	79.6[c]	80.4[b]
20	96.5[c]	96.7[d]	83.0[d]	86.2[c]

[1]Values are means of 3 replications with 4 observations averaged per replication.

[2]Thick die = 4.8 x 50.8 mm, Thin die = 4.8 x 38.1 mm.

[abcd]Column means with same superscript are not significantly different ($P < .05$).

at 10 and 20% levels of HRW but not at the 5% level.

Linear regression equations for predicting PDI as a function of % HRW for each combination of cereal base and die are listed in table 7. The equations for the sorghum, thick die, and corn, thin die, combinations appear to be quite adequate for predicting PDI as shown by their high correlation coefficients (R^2). The remaining two equations have lower R^2 values but are still useful in predicting PDI.

The PDI results in Study 1 indicate that HRW can be used effectively to improve pellet durability with either a thick or thin die. The thick die produced a higher PDI for both corn and sorghum based rations than did the thin die. This result was expected based on prior results (Pfost, 1965).

Production Rate:

Production rates for this study are shown in table 8. Production rates were determined by the weight of pellets plus fines (kg) divided by the run time (hr). No differences ($P > .05$) in production rates were found within any of the grain based die combinations at any HRW level. The corn based rations appeared to yield a higher production rate than did the sorghum based rations. This is consistent with research by Wake, (1959), who reported corn based formulas are easier to pellet and gives a higher production rate than those based on sorghum.

Energy Consumption:

Energy consumption values for Study 1 are shown in table 9. No differences ($P > .05$) in energy consumption were found between levels of HRW for any of the grain based die combinations. Statistical comparisons were not made between corn and sorghum based rations but the

TABLE 7. LINEAR REGRESSION EQUATIONS FOR PREDICTING PDI BASED ON LEVEL OF HRW, CEREAL TYPE AND DIE THICKNESS

Cereal	Die	Linear Equation	R^2
Corn	Thick[1]	PDI = 94.44 + .1011 x % HRW	.5806
Sorghum	Thick[1]	PDI = 93.44 + .1669 x % HRW	.9379
Corn	Thin[2]	PDI = 74.85 + .4213 x % HRW	.8886
Sorghum	Thin[2]	PDI = 75.47 + .5173 x % HRW	.6985

[1]Thick die = 4.8 x 50.8 mm.

[2]Thin die = 4.8 x 38.1 mm.

TABLE 8. EFFECT OF LEVEL OF HRW, DIE THICKNESS, AND CEREAL TYPE ON PELLET PRODUCTION RATE[1]

Percent HRW	Die Thickness			
	50.8 mm[2,3]		38.1 mm[2,3]	
	Corn	Sorghum	Corn	Sorghum
	(kg/hr)			
0	1423	1387	2187	1997
5	1530	1376	2166	2042
10	1502	1365	2169	2062
20	1539	1382	2172	2046

[1]Values are means of 3 replications.

[2]Thick die = 4.8 x 50.8 mm, Thin die = 4.8 x 38.1 mm.

[3]No significant differences were found within either cereal type ($P < .05$).

TABLE 9. EFFECT OF LEVEL OF HRW, DIE THICKNESS, AND CEREAL TYPE ON PELLETING ENERGY CONSUMPTION[1]

Percent HRW	Die Thickness 50.8 mm[2,3] Corn	50.8 mm[2,3] Sorghum	38.1 mm[2,3] Corn	38.1 mm[2,3] Sorghum
	(Kwh/ton)			
0	10.78	11.19	6.93	7.59
5	10.27	11.14	7.01	7.36
10	10.45	10.83	6.99	7.42
20	9.95	11.10	6.98	7.40

[1]Values are means of 3 replications with 4 observations per replication.

[2]Thick die = 4.8 x 50.8 mm, Thin die = 4.8 x 38.1 mm.

[3]No significant differences were found within either cereal type ($P < .05$).

rations containing corn appeared to have a lower energy consumption than the rations containing sorghum. These results are in agreement with Wake (1959) as previously discussed.

Moisture:

The results of moisture analysis of nonconditioned mash (NCM), conditioned mash (CM), hot pellets (HP), and cooled pellets (CP) for this study are shown in table 10. The moisture content of NCM was increased approximately 3% during conditioning for all samples. Hot pellet moistures were slightly lower than conditioned mash moistures. The increase in hot pellet moisture over conditioned mash moisture in some of the samples is probably due to analytical error or sampling variation. The final moisture content of the cold pellets was approximately .5 to 1% higher than nonconditioned mash. The moisture content of NCM was higher in the corn based thick die combination sample than in the rest of the combinations. This resulted in a cold pellet moisture above 14%. At this moisture level, conditions are favorable for insect and/or mold growth.

Temperatures:

The temperatures of NCM, CM, and HP samples for this study are shown in table 11. The NCM temperatures varied from 22 to 32 C. This degree of variability was not unexpected because the trials were conducted over a period of six months. The CM temperatures for all trials were held constant at 70 C.

SUMMARY

Experiments were conducted to determine the effects of hard red

TABLE 10. RESULTS OF MOISTURE DETERMINATIONS FOR PELLETING STUDY 1[1,2,3]

Sample	HRW Level (%) 0	5	10	20
	MOISTURE (%)			
Thick Die[4] (50.8 mm)				
Corn				
NCM	14.2	13.2	13.5	13.2
CM	17.0	16.2	16.5	16.3
HP	16.7	16.2	16.3	16.1
CP	14.7	14.2	14.3	14.4
Sorghum				
NCM	12.8	12.4	12.4	12.9
CM	15.5	15.1	15.4	15.1
HP	14.2	14.0	15.0	14.9
CP	13.7	13.4	13.3	13.3
Thin Die[4] (38.1 mm)				
Corn				
NCM	13.0	13.0	13.0	13.2
CM	15.9	15.8	15.9	15.7
HP	15.5	15.5	15.3	15.5
CP	13.4	13.4	13.6	13.2
Sorghum				
NCM	12.8	12.9	12.7	12.6
CM	15.5	15.6	15.4	15.4
HP	15.2	15.7	15.7	15.5
CP	13.5	13.6	13.8	13.7

[1]Row means are not significantly different (P < .05).

[2]Values are means of 3 replications.

[3]NCM = nonconditioned mash; CM = conditioned mash; HP = hot pellet; CP = cooled pellet.

[4]Thick die = 4.8 x 50.8 mm, Thin die = 4.8 x 38.1 mm.

TABLE 11. TEMPERATURE DATA FROM PELLETING STUDY 1[1]

Die and Cereal Type	Level of HRW (%)	Sample		
		NCM[3]	CM[4]	HP[5]
		- - - -	(OC)	- - - -
Thick die[2] (50.8 mm)				
Corn	0	22	70	76
	5	22	70	78
	10	22	70	77
	20	23	70	77
Sorghum	0	25	70	77
	5	26	70	76
	10	26	70	76
	20	25	70	76
Thin die[2] (38.1 mm)				
Corn	0	32	70	73
	5	32	70	74
	10	28	70	73
	20	30	70	73
Sorghum	0	23	70	72
	5	23	70	73
	10	23	70	72
	20	23	70	73

[1]Values are means of 3 replications.

[2]Thick die = 4.8 x 50.8 mm, Thin die = 4.8 x 38.1 mm.

[3]NCM = nonconditioned mash.

[4]CM = conditioned mash.

[5]HP = hot pellet.

winter wheat (HRW) on fines return, pellet durability, production rate and pelleting energy consumption. HRW replaced either corn or sorghum (pound for pound) in a swine ration at 0, 5, 10, and 20% levels. Comparative pelleting studies were conducted using either a thick die (4.8 mm x 50.8 mm) or a thin die (4.8 mm x 38.1 mm). Samples to be analyzed for moisture and temperature were taken before and after conditioning, after pelleting, and after cooling. Samples for Pellet Durability Index determinations were taken at the die, cooled to ambient and analyzed.

The amount of fines produced was reduced as the level of HRW in the ration increased and the use of the thin die resulted in greater fines production than did the thick die.

Pellet durability was generally improved by the addition of HRW. Increases of 3 and 10 percentage points in PDI were observed when a 20% level of HRW was pelleted with a thick and thin die, respectively.

Production rates and energy consumption were not affected by the addition of HRW; however corn based rations appeared to have a higher production rate and gave lower energy consumption results than did the sorghum based rations.

CONCLUSIONS

HRW has been shown to have beneficial effects on the pelleting process. Fines return was reduced, durability was increased, and production rate and pelleting energy consumption remained constant as the level of HRW was increased (0 to 20%). Holding production rate and pelleting energy consumption constant was a positive factor in evaluating a pelleting aid. If no positive effects were observed in fines return or pellet durability, then a pelleting aid should not be considered useful, even with a constant production rate and pelleting energy consumption. However, it has been shown that fines return decreased and pellet durability increased by adding HRW to the ration. These positive results, along with the constant production rate and pelleting energy consumption, may result in reduced manufacturing costs per ton.

EFFECT OF SOFT RED WINTER WHEAT (SRW) ON THE PELLETING PROCESS

(Study 2)

INTRODUCTION

Soft red winter wheat (SRW) is a commonly used feed ingredient. The second study was conducted to determine the effect of SRW on the pelleting process. Soft wheat was considered as a pelleting aid in this study because it is generally less expensive than the hard red winter wheat used in the first study and the structure of the endosperm of SRW is different from that of hard red winter wheat (HRW). The endosperm cell walls of SRW are thinner than those of HRW and when ground, break through the cell exposing the interior components of the starch cell. In contrast, HRW endosperm cells break at the cell wall when ground (C. Hoseney, personal communication).

EXPERIMENTAL PROCEDURE

The experimental procedure used for this study was identical to that used for the first study except; 1) SRW replaced either corn or sorghum grain (pound for pound) at 0, 5, 10, and 20% levels, 2) only the thin die (4.8 x 38.1 mm) was used for pelleting.

RESULTS AND DISCUSSION

<u>Fines return:</u>

Fines return were that portion of pelleted feed produced during the pelleting process when the pellets were cut to the desired length and by attrition when passing through the cooling and handling equipment. The amount of fines returned is a good indicator of the pellet quality of a ration. A low amount of fines indicates that the pellets are capable of withstanding the abrasive forces in the pelleting system, while a high amount of fines indicates that measures need to be taken to improve the quality of the pellets. Measures resulting in improvement may include the use of additional steam in the conditioning chamber, a different die design, better operator control, or the addition of a pelleting binder.

The effect of SRW on fines return is shown in table 12. Fines were reduced significantly ($P > .05$) when SRW was added to the corn based ration at 10 and 20% levels. Reductions of 2 and 4 percentage points below the control ration were observed at 10 and 20% SRW, respectively. No difference ($P > .05$) was found between the control and 5% SRW.

Fines were reduced by 4 and 8 percentage points at 10 and 20% SRW levels, respectively, when sorghum grain was the principle grain used in the diet. No advantage was found when SRW was used at 5% of the sorghum based diet.

The degree of reduction in fines value was greater for the higher levels of SRW in the sorghum based ration than in the corn based ration, however, sorghum based rations tended to produce more total fines than corn based rations at each level of SRW. The same observations were found in the first study with the thin die. This would indicate that a poorer quality pellet might generally result with sorghum grain based diets but that they will respond to inclusion of a binder to a greater degree.

TABLE 12. EFFECT OF LEVEL OF SRW AND CEREAL TYPE ON FINES RETURN[1]

Level of SRW (%)	Cereal Type	
	Corn	Sorghum
	- - - - - (%) - - - - -	
0	12.33[a]	18.67[a]
5	11.43[a]	17.90[ab]
10	10.07[b]	14.93[b]
20	8.13[c]	10.90[c]

[1]Values are means of 3 replications.

[abc]Column means with same superscript are not significantly different ($P < .05$).

Pellet Durability Index:

In general, as the level of SRW increased for both corn and sorghum based rations a resulting increase in PDI was observed (table 13). No differences ($P > .05$) were found between the control and 5% SRW or between 5 and 10% SRW in the corn based ration. However, a 4 percentage point increase ($P < .05$) was observed at 10% SRW and an 8 percentage point increase at 20% SRW when compared with the control.

Pellet quality for sorghum based diets was approximately 3 percentage points lower than for the corn based rations at each respective level of SRW. The SRW was found to effectively increase pellet quality in the sorghum rations. No difference in PDI was shown between the 5 and 10% levels of SRW but each level of SRW (5, 10, and 20%) improved PDI over that observed for the control.

Linear regression equations were calculated for predicting PDI as a function of SRW level with either corn or sorghum grain based diets and are listed in table 14. It appears that the PDI can be effectively predicted based on the fact that the regression coefficients are relatively high.

Production Rate:

Production rates for the second study are shown in table 15. No difference ($P > .05$) in production rates was observed between any level of SRW for either corn or sorghum based rations. Statistical comparisons were not made between corn and sorghum rations; but the corn rations appear to have a higher production rate than sorghum rations. This trend was also observed in the earlier study using HRW.

TABLE 13. EFFECT OF LEVEL OF SRW AND CEREAL TYPE ON PELLET DURABILITY INDEX[1]

Level of SRW (%)	Cereal Type	
	Corn	Sorghum
	- - - - - (%) - - - - -	
0	80.2[a]	76.6[a]
5	82.2[ab]	79.3[b]
10	84.1[b]	81.5[b]
20	88.1[c]	85.6[c]

[1]Values are means of 3 replications with 4 observations per replication.

[abc]Column means with same superscript are not significantly different ($P < .05$).

TABLE 14. LINEAR REGRESSION EQUATIONS FOR PREDICTING PDI BASED ON LEVEL OF SRW AND CEREAL TYPE[1]

Cereal Type	Linear Equation	R^2
Corn	PDI = 80.17 + .3964 x % SRW	.8436
Sorghum	PDI = 76.85 + .4463 x % SRW	.9225

[1]4.8mm x 38.1 mm die was used.

TABLE 15. EFFECT OF LEVEL OF SRW AND CEREAL TYPE ON PELLET PRODUCTION RATE[1,2]

Level of SRW (%)	Cereal Type	
	Corn	Sorghum
	- - - - (kg/hr)	- - - -
0	2240	2038
5	2269	2052
10	2320	2051
20	2310	2025

[1]Values are means of 3 replications.

[2]Column means are not significantly different ($P < .05$).

Energy Consumption;

SRW had no effect on energy consumption in either the corn or sorghum based rations (table 16). Although statistical comparisons were not made between corn and sorghum rations, corn rations appeared to use less energy during pelleting than sorghum based rations. The same observations were made in the earlier study involving HRW and are consistent with research by Wake, (1959).

Moisture:

Moisture analysis by an air oven were made on nonconditioned mash (NCM), conditioned mash (CM), hot pellets (HP), and cold pellets (CP). The results are shown in table 17. The moisture content of NCM was increased approximately 3% during conditioning for all samples. Hot pellet moistures were slightly lower than conditioned mash moistures due to moisture evaporation immediately after pelleting. The increase in hot pellet moisture over conditioned mash moisture in some of the samples is probably due to analytical error or sampling variation. The final moisture content of cold pellets was found to be approximately .5 to 1% higher than nonconditioned mash.

Temperature:

The temperatures for NCM, CM, and HP for this study are shown in table 18. The temperature of the NCM samples were the same for both corn and sorghum based rations. Since the trials were conducted during the same week, similar NCM temperatures would be expected. Temperature of the conditioned mash for both trials were held constant at 70 C and the temperature rise due to pelleting was respectively, 3 and 4 C in corn and sorghum rations. The temperature rise due to pelleting is caused

TABLE 16. EFFECT OF LEVEL OF SRW AND CEREAL TYPE ON PELLETING ENERGY CONSUMPTION[1,2]

Level of SRW (%)	Cereal Type	
	Corn	Sorghum
	---- (Kwh/ton) ----	
0	6.76	7.52
5	6.76	7.38
10	6.61	7.37
20	6.56	7.57

[1]Values are means of 3 replications.

[2]Column means are not significantly different ($P < .05$).

TABLE 17. RESULTS OF MOISTURE DETERMINATIONS FOR PELLETING STUDY 2[1,2,3]

Sample	Level of SRW (%)			
	0	5	10	20
	- - - - - - - Moisture (%) - - - - - - -			
Corn based diet				
NCM	12.8	12.6	12.7	12.5
CM	15.8	15.2	15.7	15.7
HP	14.9	14.8	15.5	15.0
CP	13.6	13.2	13.5	13.5
Sorghum grain based diet				
NCM	12.3	12.8	12.7	12.4
CM	15.5	15.8	15.5	15.4
HP	15.2	15.6	15.5	15.4
CP	13.2	13.4	13.4	13.4

[1]Row means are not significantly different ($P < .05$).

[2]Values are means of 3 replications.

[3]NCM = nonconditioned mash; CM = conditioned mash; HP = hot pellet; CP = cooled pellet.

TABLE 18. TEMPERATURE DATA FROM PELLETING STUDY 2[1,2]

Grain	Level of SRW (%)	Sample[3] NCM	CM	HP
		- - - - (^{o}C)	- - - -	
Corn based diet				
	0	21	70	73
	5	20	70	73
	10	20	70	73
	20	20	70	73
Sorghum grain based diet				
	0	20	70	74
	5	20	70	74
	10	20	70	74
	20	20	70	74

[1]Values are means of 3 replications.

[2]Column means for each grain are not significantly different ($P < .05$).

[3]NCM = nonconditioned mash; CM = conditioned mash; HP = hot pellet.

by mechanical friction between the mash and the pellet die during the extrusion of the pellet.

SUMMARY

Experiments were conducted to determine the effects of soft red winter wheat (SRW) on fines return, pellet durability, production rates and energy consumption. The SRW replaced either corn or sorghum in a swine ration at 0, 5, 10, and 20% levels. A thin die (4.8 mm x 38.1 mm) was used to pellet both the corn and sorghum based rations.

The amount of fines were reduced as the level of SRW in the ration increased in the corn and sorghum rations. A more significant increase was observed at higher levels of SRW. Pellet durability was also improved by the addition of SRW. Increases of 8 and 9 percentage points at 20% SRW were observed for corn and sorghum rations, respectively. Production rate and energy consumption were not affected by the additon of SRW. However, corn based rations appeared to result in a higher production rate and use less energy than sorghum based rations.

CONCLUSIONS

Soft red winter wheat had positive effects on the pelleting process. Fines returned were reduced, durability was increased, and production rate and pelleting energy consumption remained constant as the level of SRW increased from 0 to 20%. As stated in the conclusions of the previous study, these positive effects could result in improved manufacturing costs per ton due to fewer fines being returned to the pellet mill for repelleting.

EFFECT OF B-GRADE WHEAT STARCH (BGS) EXTRUSION PROCESSED SECOND CLEARS FLOUR (SCF), SODIUM BENTONITE (SB) AND CALCIUM LIGNOSULFONATE (CLS) ON THE PELLETING PROCESS

(Study 3)

INTRODUCTION

Sodium bentonite (SB) and calcium lignosulfonate (CLS) as pellet binders have been shown to improve pellet quality (Heideman, 1962; Olentine, 1980; Stevens, 1962; and Pfost, 1965). Heideman, (1962) showed CLS improved pellet durability and the production rates of the pellet mill. Pfost (1965) reported a reduction in power requirements and improved pellet durability when using CLS as a pellet binder. Stevens (1962) showed that pellet durability was increased by the use of SB with no effect on pelleting energy consumption.

The objective of this study was to compare pelleting parameters such as percentage of fines, pellet durability, production rate and energy consumption when comparing SB and/or CLS with two wheat products; B-grade wheat starch (BGS) and an extrusion processed second clears flour (SCF).

B-grade starch and second clears flour were compared to sodium bentonite and calcium lignosulfonate to determine if these wheat products effected pellet quality without adversely effecting production rate and pelleting energy consumption and also to determine if they are as effective as sodium bentonite and calcium lignosulfonate. Particle size of the pelleting aids were measured to determine if there was any effect in particle size between pelleting aids on pelleting parameters.

EXPERIMENTAL PROCEDURE

The experimental procedures used for this study were identical to that previously described (Study 1) except for the following: 1) a thin die (4.8 mm x 38.1 mm) was the only die used for pelleting, 2) corn was the only grain used in the ration, 3) BGS, SCF, SB, and CLS were substituted for corn (pound for pound) in the control diet at 1.5 and 3.0% for BGS, 2.5% for SCF, 2.5% for SB, and 2.5% for CLS, 4) particle sizes were determined by the method described by Pfost and Headley (1976), 5) the experimental design used was a randomized complete block design with six treatments in each of three blocks. Results were statistically analyzed using analysis of variance (ANOVA) and Duncan's Multiple Range Test (SAS, 1979).

RESULTS AND DISCUSSION

Fines Return:

Fines that would normally be returned to the pellet mill were collected and the percentage of production was determined for each run (table 19). The results of this study showed no difference ($P > .05$) between the control, SCF, 1.5% BGS, and 3.0% BGS. No difference was shown between CLS and SB; but both CLS and SB reduced ($P < .05$) fines below that of the other treatments examined.

Pellet Durability:

Pellet quality evaluation results (PDI) for this study are shown in table 20. Since fines were not reduced by the addition of the wheat products (SCF and BGS), it was expected that they would have little affect in improving PDI. This was the case except for 3.0% BGS where

TABLE 19. EFFECT OF SCF, BGS, CLS, AND SB ON FINES RETURN[1,2]

Pellet Aid	Use Level (%)	Fines (%)
Control	0	17.46[a]
SCF	2.5	17.31[a]
BGS	1.5	15.84[a]
BGS	3.0	14.52[a]
CLS	2.5	10.28[b]
SB	2.5	9.71[b]

[1]Values are means of 3 replications.

[2]A 4.8 x 38.1 mm die was used for this trial.

[ab]Means with same superscript are not significantly different ($P < .05$).

TABLE 20. EFFECT OF SCF, BGS, CLS, AND SB ON PELLET DURABILITY[1,2]

Pellet Aid	Use Level (%)	PDI (%)
Control	0	77.02[a]
SCF	2.5	77.63[a]
BGS	1.5	78.62[a]
BGS	3.0	81.63[b]
CLS	2.5	87.55[c]
SB	2.5	88.70[c]

[1]Values are means of 3 replications with 4 observations per replication.

[2]A 4.8 x 38.1 mm die was used for this trial.

[abc]Means with same superscript are not significantly different ($P < .05$).

PDI was increased ($P < .05$) by approximately 3 percentage points over the lower level of BGS, SCF, and the control. CLS and SB were the most effective in this study in improving PDI. Although no difference was shown between CLS and SB, PDI was increased ($P < .05$) by 6 to 11 percentage points over the control, SCF and BGS. The above indicates that wheat products at low levels neither worked effectively at reducing fines nor at improving pellet durability and did not improve PDI as much as CLS or SB.

Production Rate:

Production rate values for this study are shown in table 21. No differences ($P > .05$) in this parameter were found between the control and any of the wheat products. Similar observations were made in two previous studies in which HRW and SRW wheat were evaluated. However, CLS increased ($P < .05$) and SB decreased ($P < .05$) production rate from that found for the control. The increase was consistent with research by Heideman (1962) who reported a 6% increase in production rate with a 2% use level of CLS.

Energy Consumption:

No differences ($P > .05$) in energy consumption were found between any of the wheat products or SB (table 22). The only significant effect was from the use of CLS which resulted in a decrease in energy consumption. This observation was consistent with research by Pfost (1965) who reported a reduction in power requirements when CLS was used as a pelleting aid.

Moisture:

The moisture content of NCM for each treatment was increased approximately 3% during conditioning (table 23). Hot pellet moistures were

TABLE 21. EFFECT OF SCF, BGS, CLS, AND SB ON PRODUCTION RATE[1,2]

Pellet Aid	Use Level (%)	Production Rate (kg/hr)
Control	0	2099[a]
SCF	2.5	2152[a]
BGS	1.5	2085[a]
BGS	3.0	2114[a]
CLS	2.5	2341[b]
SB	2.5	2051[c]

[1] Values are means of 3 replications.

[2] A 4.8 x 38.1 mm die was used for this trial.

[abc] Means with same superscript are not significantly different ($P < .05$).

TABLE 22. EFFECT OF SCF, BGS, CLS, AND SB ON PELLETING ENERGY CONSUMPTION[1,2]

Pellet Aid	Use Level (%)	Energy Consumption (Kwh/ton)
Control	0	7.22[a]
SCF	2.5	7.04[a]
BGS	1.5	7.27[a]
BGS	3.0	7.43[a]
CLS	2.5	6.47[b]
SB	2.5	7.49[a]

[1]Values are means of 3 replications.

[2]A 4.8 x 38.1 mm die was used for this trial.

[ab]Means with same superscript are not significantly different ($P < .05$).

TABLE 23. RESULTS OF MOISTURE DETERMINATIONS FOR PELLETING STUDY 3[1,2,3]

Sample	Treatment					
	Control	SCF	BGS(1.5%)	BGS(3.0%)	CLS	SB
	(%)					
NCM	12.8	12.8	12.8	12.9	12.8	12.8
CM	16.4	15.6	15.5	15.9	15.7	15.5
HP	15.5	15.5	15.5	16.0	15.7	15.7
CP	13.4	13.4	13.4	13.5	13.5	13.4

[1]Row means are not significantly different ($P < .05$).

[2]Values are means of 3 replications.

[3]NCM = nonconditioned mash; CM = conditioned mash; HP = hot pellet; CP = cooled pellet.

either slightly lower or higher than conditioned mash moistures. The increase in hot pellet moisture over conditioned mash moisture is probably due to analytical error or sampling variation. The final moisture content of the cold pellets was found to be approximately .5% higher than nonconditioned mash. This is consistent with the two previous trials.

Temperature:

The temperatures of NCM, CM, and HP samples for this study are shown in table 24. NCM temperatures for the NCM samples were constant for all treatments, thus, a 50 C temperature rise for all samples during conditioning of the mash was observed. The temperature rise due to pelleting varied from 0 to 3 C. No temperature rise was observed when CLS was used as the pelleting aid. No statistical difference was found in the temperature rise due to pelleting for any of the treatments.

Particle Size:

The results of particle size analysis of the pelleting aids used in this study are shown in table 25. Mean particle diameter, geometric standard deviation, surface area, and particles per gram were calculated by the use of a computer program developed specifically for particle size analysis.

No difference ($P > .05$) in mean particle diameter was observed between CLS and BGS. It was difficult to measure the particle size of CLS because of the adhesiveness of the product to the sieves. The actual size was probably smaller than reported. SB was shown to have the smallest mean particle diameter and the largest surface area and number of particles per gram.

TABLE 24. TEMPERATURE DATA FROM PELLETING STUDY 3[1,2,3]

Sample	Treatment					
	Control	SCF	BGS(1.5%)	BGS(3.0%)	CLS	SB
	(^{o}C)					
NCM	20	20	21	21	20	20
CM	70	70	70	70	70	70
HP	72	72	71	71	70	73

[1]Row means are not significantly different ($P < .05$).

[2]Values are means of 3 replications.

[3]NCM = nonconditioned mash; CM = conditioned mash; HP = hot pellet.

TABLE 25. PARTICLE SIZE ANALYSIS OF THE PELLET AIDS USED IN STUDY 3[1]

Pellet Aid	Mean Particle Diameter (μ)	Geometric STD Deviation	Surface Area (cm^2/gm)	Particle No. (Particles/gm)
SCF	180^a	1.89	303^a	$794,458^a$
CLS	143^b	1.61	336^a	$674,999^b$
BGS	133^b	2.02	413^b	$2,820,817^c$
SB	55^c	1.56	481^c	$5,806,666^d$

[1] Values are means of 2 replications.

[abcd] Means with same superscript are not significantly different ($P < .05$).

As mean particle size is reduced, more surface area is exposed to steam during conditioning. This allows for more uniform absorption of steam (Smith, 1962) and because steam is absorbed more uniformly, greater adhesive forces should be attained between the mash particles. Greater adhesive forces would decrease fines return and increase pellet durability. This was the case with SB which had the smallest mean particle diameter, produced the least amount of fines and had the highest pellet durability in this study. If the assumption that CLS mean particle diameter is actually smaller than reported is true, then the above statements relating mean particle size of the pellet binder to fines return and pellet durability would also be true for CLS.

SUMMARY

Experiments were conducted to determine the effects of extrusion processed second clears wheat flour and B-grade wheat starch on pellet quality, production rates and energy consumption. The data from the wheat products were compared to data generated from using pelleting aids of known binding capabilities; calcium lignosulfonate and sodium bentonite.

B-grade wheat starch and second clears flour did not reduce fines while calcium lignosulfonate and sodium bentonite did. This was expected because these two pelleting aids are known for their binding ability.

B-grade starch at the 3.0% usage level was the only wheat product to significantly improve pellet durability. Again, calcium lignosulfonate and sodium bentonite performed well as binding agents in terms of improved pellet quality.

Production rates and energy consumption were uneffected by addition of wheat products. Calcium lignosulfonate increased production rate and decreased energy consumption while sodium bentonite decreased production rates with no significant effect on energy consumption.

CONCLUSIONS

The wheat products examined in this study did not significantly ($P < .05$) improve pellet quality. The greatest positive effect that was observed was an increased pellet durability with B-grade wheat starch at 3.0%. However, BGS was not equal to calcium lignosulfonate or sodium bentonite in binding ability. Based on the results of this study, the wheat products tested were not effective as pelleting aids at the level they were used in these experiments.

The increase in production rate with calcium lignosulfonate and corresponding reduction in fines returned indicated a lower manufacturing cost per ton with this additive than with the control ration. The lower production rate with sodium bentonite would result in an increased manufacturing cost per ton, however this increase may be offset by the increase in pellet durability and the decrease in fines return.

LITERATURE CITED

AOAC. 1970. Official Methods of Analysis (11th Ed.). Association of Official Analytical Chemists. Washington, D. C.

Heideman, A.G. 1962. The effect of binding agents on pellet durability. In Cost Reductions Through In-Plant Production Controls. Proceedings of 1962 Feed Production School. p. 51.

Olentine, C.G. Jr. 1980. Pelleting aids. Feed Management. 31:11 p. 8.

Pfost, H.B. 1965. The effect of lignin binders, die thickness and temperature on the pelleting process. Feedstuffs 36:20.

Pfost, H.B. 1976. Wafers, pellets and crumbles-definitions and methods for determining specific weight, durability and moisture content. In H.B. Pfost (Ed.) Feed Manufacturing Technology. A.F.M.A. Arlington, Virginia p. 527.

Pfost, H.B. and V.E. Headley. 1976. Methods of expressing and determining particle size. In H.B. Pfost (Ed.) Feed Manufacturing Technology. A.F.M.A. Arlington, Virginia p. 512.

SAS. 1979. SAS User's Guide. SAS Institute Inc. Cary, North Carolina.

Smith, G.M. Jr. 1962. The effect of particle size. In Cost Reductions Through In-Plant Production Controls. Proceedings of 1962 Feed Production School. p. 47.

Stevens, C. Jr. 1962. Effect of binders, steam and particle size on pelleting. In Cost Reductions Through In-Plant Production Controls. Proceedings of 1962 Feed Production School. p. 40.

Wake, P.C. 1959. Complete ration pellets for poultry and swine. In Pelleting and Related Subjects. Proceedings of 1959 Feed Production School. p. 14.

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EFFECTS OF HARD AND SOFT RED WINTER WHEAT AND WHEAT PRODUCTS ON THE PELLETING PROCESS

by

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ABSTRACT

Research was conducted to determine the effects of various pelleting aids and agents on fines return, pellet durability, production rates and pelleting energy consumption. The pelleting aids that were examined were hard red winter wheat, soft red winter wheat, B-grade wheat starch, second clears flour, calcium lignosulfonate and sodium bentonite. This research project was conducted in three separate studies. Study one involved the use of hard red winter wheat as a pelleting aid at 0, 5, 10, and 20% levels in a swine ration. A 4.8 mm x 50.8 mm and a 4.8 mm x 38.1 mm die were used to pellet both corn and sorghum based rations.

The second study involved the use of soft red winter wheat as a pelleting aid at 0, 5, 10, and 20% levels in the same swine ration used for study 1. Only the 4.8 mm x 38.1 mm die was used to pellet the rations in this study.

The third study involved the use of B-grade wheat starch, extrusion processed second clears flour, calcium lignosulfonate and sodium bentonite as pelleting aids at 1.5 and 3.0%, 2.5, 2.5%, and 2.5%, respectively. The ration formulation used was identical to that in Studies 1 and 2. No attempt was made to evaluate the economic aspects of the results due to the large variability in ingredient prices and production costs depending upon geographic location.

Fines were reduced as levels of wheat were increased in the ration. B-grade wheat starch and second clears flour failed to reduce fines; however calcium lignosulfonate and sodium bentonite resulted in reduced fines return. These results were expected because these two pelleting

aids are known for their pellet binding ability.

Pellet durability increased as the level of either class of wheat increased. The only increase in pellet quality observed for the wheat products was with B-grade wheat starch at a 3.0% level. Again, calcium lignosulfonate and sodium bentonite performed well as binding agents in terms of pellet durability. Pellet durability increases of 10 to 11% were observed when these two pelleting aids were used.

In general, production rates and energy consumption were uneffected by addition of wheat or wheat products. The use of calcium lignosulfonate resulted in increased production rate and decreased energy consumption while sodium bentonite addition resulted in decreased production rates with no effect on energy consumption.

In all phases of this study, mash temperature rise was controlled to approximately 50 C during conditioning. This temperature rise corresponded to a 3% increase in moisture. A greater temperature rise might have increased pellet durability, decreased fines return, increased production rates, or decreased energy consumption; however any additional temperature rise above that used would choke the pellet mill.