USE OF AGRONOMIC CONDITIONS, GENETICS, AND PROCESSING TO IMPROVE UTILIZATION OF SORGHUM GRAIN[1]

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Summary

Sorghum grain is an extremely important crop to both farmers and livestock feeders in the High-Plains states (e.g., from Nebraska to Texas). Kansas leads the nation in sorghum production, and as should be expected, Kansas State University has a long history of research to improve the utilization and marketability of this versatile and hardy crop. This paper is a synopsis of current research at KSU and other universities concerning production and use of sorghum grain for feeding swine. Topics addressed include the relatively small loss in nutritional value (4 to 11%) as test weight decreases from 55 to 35 lb/bu compared to the extreme discounts experienced by farmers trying to market light grain. Also, an experiment to quantitate yield of utilizable nutrients from corn and sorghum was conducted to determine the relative merits of these grain sources when grown with different irrigation and N application strategies. Finally, sorghum parent lines have been identified with improved digestibility, and alternative milling procedures (e.g., fine-grinding and extrusion) have been identified that should greatly improve the competitiveness of sorghum grain as a feedstuff of choice for swine diets.

(Key Words: Sorghum Grain, Irrigation, N Application, Genotype, Process, GF, Starter.)

Introduction

For centuries, sorghums have been produced in Third-World countries for human consumption with selection based largely on ease of milling and aesthetic value. In contrast, plant breeders in developed countries have focused almost entirely on yield characteristics, including resistance to disease, drought and insects. Unfortunately, very little emphasis has been given to development of sorghums superior for their ultimate fate, that is, their utilization as nutrient sources for livestock and humans. This paper is a review of environmental factors, genotypic traits, and processing procedures that affect quality and availability of nutrients provided by sorghum grain. Attention is given to means that can be used to maximize the feeding value of sorghum grain, thus increasing its utility in swine feeding.

Discussion

Agronomic Conditions. It is important to recognize that considerable variability in nutrient content and quality does exist in sorghum grain. The same factors that are forcing a re-evaluation of corn production in many areas (e.g., frequent droughts, unpredictable length of growing season, limited water supply, low soil fertility, etc.) undoubtedly cause the majority of the variation in nutrient content and quality of sorghum grain produced in these

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areas. Researchers in Oklahoma sampled grain from 15 sorghum varieties grown in 2 consecutive years at five locations. Crude protein ranged from 10.9 to 16.5%, and lysine as a percentage of crude protein ranged from 1.9 to 2.3%. In a similar experiment at KSU, 100 sorghums were grown at two locations, with and without irrigation at one location, and with low versus high N application at a second location. Crude protein content ranged from 6.7 to 14.3%, and in vitro protein digestibility (pepsin digest) ranged from 59.9 to 82.6%. The question then becomes, would those differences in nutrient content and in vitro digestibility be reflected in differences in growth performance of pigs consuming the grain? Secondly, what factors might be controlled and(or) manipulated to minimize those differences in nutritional value?

One commonly occurring factor affecting nutrient content and quality of sorghum grain that cannot be controlled is frost damage. An experiment designed to test the effects of early frost on the nutritional value of sorghum grain for growing-finishing pigs was reported by researchers at Texas Tech University. As test weight increased from 32 to 48 lb/bu, rate and efficiency of gain increased by 6 and 8%, respectively, but increasing test weight to 56 lb/bu did not further improve growth performance. Indeed, pigs fed the sorghum with intermediate test weight had numerically the greatest rates and efficiencies of gain. Similar results were reported by scientists at Kansas State University and South Dakota State University in 1990 and 1991. An early frost in the fall of 1989 resulted in sorghum with test weights from 30 to 60 lb/bu produced in the same one-county area near Garden City, KS. Sorghums with normal, intermediate, and light test weights (55, 45, and 35 lb/bu, respectively) were purchased from several producers and blended within test weight. As test weight decreased from normal to light, crude protein concentration of the sorghum grain increased from 9.7 to 11.5%. There was more than a 3-fold increase in percentage crude fiber as test weight decreased from normal to light. In growing and finishing pigs, the intermediate sorghum was equal to normal sorghum for rate and efficiency of gain. However, the blend of normal and light sorghums was of lower nutritional value than the intermediate sorghum, especially for finishing pigs. These results indicate that current recommendations of blending normal and light test weight sorghums to obtain optimum growth performance should be re-evaluated. Perhaps an even more important observation is that the reductions in feeding value of the light test weight sorghum (4% in chicks, 11% in growing pigs, 7% in finishing pigs, and equal feeding value in growing cattle) is not indicative of the severe penalties in price paid for those sorghums. However, this still leaves the question of what can be done to optimize the nutritional value of sorghum grain by manipulation of factors that can be controlled.

Experiments with well defined growing conditions for cereal grains produced at the same location are difficult to find. A limited number of such experiments have been reported with corn, indicating that both irrigation and N fertilization affect the yield and quality of nutrients in normal and high lysine corn. KSU researchers reported similar results for sorghums raised under varied agronomic conditions (Table 1). Treatments were corn, bronze pericarp hetero-yellow endosperm sorghum grain (BSG), and a yellow pericarp homozygous-yellow endosperm sorghum grain (YSG) grown with optimum or minimum irrigation, with or without N application. The grains were produced on a small scale and, thus, chick assays were used to model the probable responses in pigs. This project was targeted especially for the farmers/feeders who market their sorghum grain through their own swine operations. When averaged across irrigation and fertilization treatments (Experiment 1), G/F of chicks fed the corns was not different than G/F of chicks fed the sorghums. However, chicks fed the BSG had improved G/F compared to chicks fed YSG. The greater feeding value of BSG was confirmed in a separate experiment to determine ME_n of the grain treatments (Experiment 2), with lower ME_n for YSG than BSG. Evaluation of the grain treatments for protein quality, using a modified chick PER assay (Experiment 3), indicated that corn was not different than the sorghums and that the protein of YSG was of greater quality than the protein of BSG. Optimum irrigation increased yield by 44%, and N application increased yield by 9%. Yield of utilizable nutrients (yield × G/F), utilizable energy (yield × ME_n), and utilizable protein (CP yield × G/F) were affected more by irrigation than N application, with grain source having only a minimal effect. However, interactions between grain source, irrigation level, and N application indicated that water stress resulted in greater loss of utilizable nutrient yield for corn and YSG than BSG. Also, both sorghums yielded more utilizable nutrients than corn at comparable levels of added irrigation, because water applied was similar for the low-irrigation corn treatments and the optimum-irrigation sorghum treatments (i.e., total moisture from rain and irrigation was 37.4 in for optimum-corn, 28.0 in for low-corn, 31.5 in for optimum-sorghum, and 20.9 in for low-sorghum). These results favor use of sorghum to maximize nutrient yield in areas of limited rainfall and(or) a dwindling supply of water for irrigation. Comparing the sorghums produced without irrigation, the BSG had greater feeding value (G/F in Experiment 1), but the YSG had greater protein quality (G/F in Experiment 3). However, the greater yield of BSG resulted in greater yield of UN and UP compared to YSG. Thus, the current concerns about improved feeding value with yellow pericarp and(or) homozygous-yellow endosperm sorghums seems unfounded. Other genetic factors would seem to merit more attention than pericarp color and endosperm color.

Table 1. Effects of Agronomics on Yield of Utilizable Nutrients from Corn and Sorghums[a,b]

	Corn				Bronze sorghum				Yellow sorghum			
	Irr		Low-Irr		Irr		Low-Irr		Irr		Low-Irr	
Item[c]	+N	-N	+N	-N	+N	-N	+N	-N	+N	-N	+N	-N
Exp. 1												
Yield, kg/ha	7601	7272	5687	5197	7937	6597	5790	5229	8427	7802	4827	4865
G/F	.710	.712	.716	.693	.723	.741	.725	.716	.668	.693	.705	.697
UN, kg/ha	5397	5178	4072	3602	5738	4888	4198	3744	5629	5407	3403	3391
Exp. 2												
GE yield, Gcal/ha	31.5	30.7	23.6	21.7	32.8	27.3	24.0	21.9	34.6	32.4	19.7	19.7
ME_n, kcal/kg	3593	3282	3137	3314	3699	3323	3187	3484	3315	3610	3111	2977
UE yield, Gcal/ha	27.3	23.9	17.8	17.2	29.4	21.9	18.5	18.2	27.9	28.2	15.0	15.5
Exp. 3												
CP yield, kg/ha	671	601	508	481	821	609	609	544	752	665	462	468
G/F	.645	.646	.651	.658	.635	.638	.607	.633	.661	.652	.647	.654
UP, kg/ha	433	388	331	317	521	389	370	344	497	434	299	306

[a]Adapted from Richert et al. (1991).
[b]Treatment abbreviations are Irr = irrigated, Low-Irr = minimum irrigation, +N = with N application, -N = without N application.
[c]Item abbreviations are UN = utilizable nutrients (G/F × yield), GE = gross energy, ME_n = metabolizable energy, UE = utilizable energy (ME_n × yield), UP = utilizable protein (G/F × protein yield).

Genotype. The nutritional value of various fairly simply inherited traits, such as pericarp color and endosperm color, type, and texture, have been investigated. Researchers in Arkansas reported that sorghums with yellow pericarp were better utilized by nursery pigs (fed from 10 to 20 kg body weight) than sorghums with brown pericarp, but the latter had high tannin content (i.e., .67% vs .22% for the brown and yellow sorghums, respectively). Simple correlation coefficients were -.68 and -.58 between tannin content and digestible energy and digestible protein, respectively. Thus, these experiments did not address the issue of differences in nutritional value between sorghums with different pericarp colors but similar tannin content. In a Nebraska experiment, sorghums with bronze, cream, and yellow pericarp colors were compared to corn for feeding nursery and growing-finishing pigs. Nursery pigs gained 5 to 8% slower with all sorghum types but with similar efficiency to pigs fed corn. In a growing-finishing experiment, pigs fed the sorghums gained 4% slower and were 4 to 9% less efficient than pigs fed corn. The authors concluded that reduced palatability of sorghums may be more of a problem in very young animals and reduced energy value more of a problem in older animals, but no consistent differences were due to pericarp color.

In contrast to pericarp color, differences in endosperm characteristics have been suggested to affect nutritional value. There are reports in ruminants of higher nutritional value for sorghums with yellow versus white endosperm color. However, it is most difficult to rationalize why digestive enzymes might prefer endosperm with yellow pigmentation. It's more probable that early experiments reporting differences among sorghums with different endosperm colors actually may have been comparisons of differences in endosperm type and texture.

Studies with ruminants and in vitro experiments indicate improved digestibility for waxy endosperm type and floury endosperm texture, but pig experiments at Texas A&M have shown no differences in dry matter, energy, or protein digestibility for waxy versus normal sorghums. Furthermore, comparison of sorghums with floury, intermediate, and corneous endosperm indicated that intermediate endosperm was superior to floury endosperm for both dry matter and energy digestibility. Sorghums with floury and corneous endosperm had similar digestibilities. Florida researchers compared sorghum grain with waxy and normal endosperm types and low, medium, and high tannin content fed to nursery pigs. As tannin content increased, rate and efficiency of gain decreased, but sorghum with waxy endosperm was no better nutritionally than sorghum with normal endosperm.

The lack of improvement in energy digestibility and utilization in swine fed floury and waxy endosperm sorghums and the realization that very soft or floury sorghums have reduced yield and poor weathering ability have stimulated research at KSU into the relationship of yield and digestibility. Direct selection was made in a sorghum population for improved in vitro protein digestibility (digestibility in pepsin) from 100 S_1 families, which were grown at five locations for 2 years. Growing conditions greatly influenced sorghum digestibility, and higher protein digestibility was associated with lower yield and later maturity. In view of these undesirable relationships, a selection index was developed to include the rank for yield plus the rank for digestibility minus the rank for bloom date, with selection restricted to families in the top 50% for yield and protein digestibility. Heritability for this index was 38%, and it identified 20 families with improved protein digestibility, better grain yield, and earlier maturity. From this population, two lines were selected with consistently low in vitro digestibility and two lines with consistently high in vitro digestibility. When these sorghums were fed to growing-finishing pigs that were fitted with ileal cannulas, digestibility of gross energy increased from 74% for the low digestibility sorghums to 77% for the high digestibility sorghums, compared to a digestibility of 80% for corn. In chick feeding assays, these lines, respectively, supported rates of gain that were 95, 96, 98, and 100% that of the corn control and efficiencies of gain that were 95, 97, 98, and 100% that of the corn control. Overall, the authors concluded that use of in vitro protein digestibility, in conjunction with yield and maturity date, has potential to genetically improve grain sorghum as a feed grain for livestock, even though the environment will still have a major effect on nutritional quality. Unlike selection for floury and waxy endosperm, this selection index would result in genetic material for use in hybrids with acceptable yield, maturity, and weathering ability and improved nutritional value for pigs.

Processing. Handling/processing techniques have included grinding, crushing, steaming, steam flaking, popping, and extruding. During the past 2 years, we have conducted experiments showing that extrusion processing of sorghum grain improved nutrient digestibility and efficiency of growth in finishing pigs (Figure 1). Texas A&M researchers reported a linear improvement in ileal and total tract energy digestibility in growing pigs as particle size of sorghum was reduced from approximately 1,300 to 600 μm by hammermilling. Researchers here at KSU reported similar findings, in that nitrogen and dry matter digestibilities and efficiency of gain for pigs fed corn and sorghum grain improved linearly as particle size was reduced from greater than 1,000 μm to below 700 μm. Thus, extrusion and reducing particle size did seem to improve the feeding value of sorghum grain for swine.

In a direct comparison of the effects of coarse grinding and fine grinding of different cereal grains (corn, yellow sorghum, and bronze sorghum), Nebraska researchers reported that fine grinding (600 vs 1200 μm) improved efficiency of gain in finishing pigs fed corn or yellow sorghum, and that dry matter and nitrogen digestibilities were improved more by fine grinding of the sorghums than for corn. Data from our laboratory indicate that power usage was two to four times greater to roller mill corn than hard and soft endosperm sorghum grain, at particle sizes ranging from 900 to 500 μm (Figure 2). When these grains were fed to weanling pigs (Figure 3), optimum F/G was at 300 μm for d 0 to 7 and 500 μm for d 0 to 35. When milled to their optimum particle sizes, feeding values of hard and soft sorghum grains were 105 and 93% that of corn from d 0 to 7 and 94% that of corn from d 0 to 35. From these data, we concluded that weanling pigs responded more to fine grinding (300 to 500 μm) early in the growth phase. Perhaps most important was showing that the sorghums could be milled to 500 μm with less energy cost and greater tonnage/h than required to mill corn to 900 μm. Thus, finely ground sorghum (300 to 500 μm) merits serious consideration as an alternative to corn in diets for early-weaned pigs (for 2 wk post-weaning). It should be noted that these results were from feeding pelleted diets, thus the problems reported with bridging and reduced flowability in diets with small particle size were not a concern. A complete report of this project can be found elsewhere in these proceedings (Healy et al.).

In conclusion, sorghum is an excellent feedstuff for swine. Although the feeding value of sorghum is on average 3 to 7% less than that of corn, cost of sorghum in many areas is commonly 10 to 15% less than the cost of corn. In addition to the current economic and environmental incentives for using sorghum, scientists are improving its feeding value through plant breeding, increased understanding of agronomic practices, and improved milling and processing procedures that will result in optimum nutritional value. With these advances and with the superior sustainability of sorghum production with minimal rainfall, the future of sorghum as a major feed grain for use by Kansas swine producers seems promising.

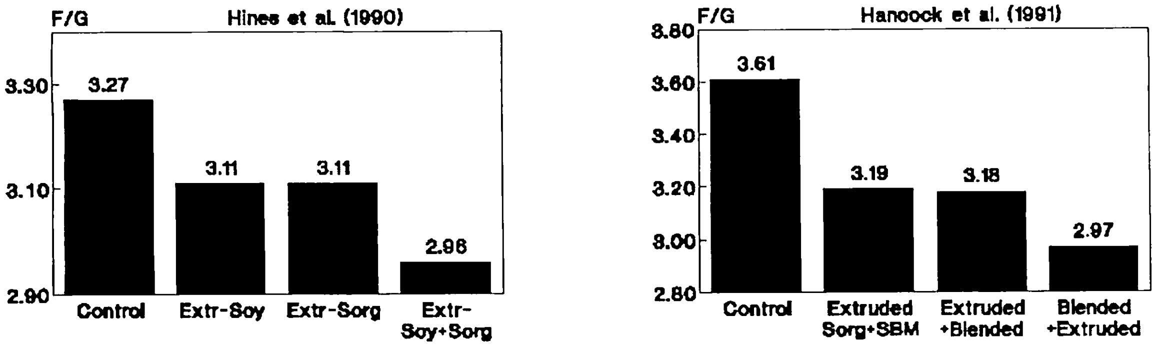
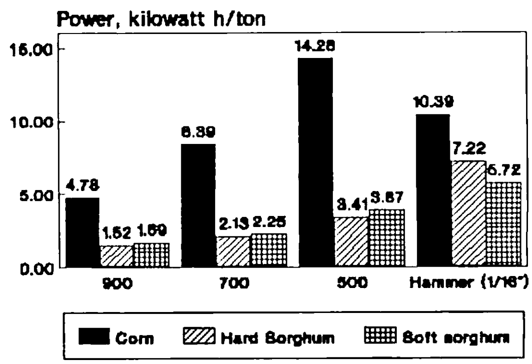


Figure 1. Replacing Ground Sorghum, Soybean Meal, and Soybean Oil with Extruded Sorghum, Extruded Soybean Meal, and Extruded Soybeans in Diets for Finishing Pigs. Treatments for Hines et al. were: Control = ground sorghum, soybean meal and soybean oil; Extr-Soy = ground sorghum and extruded soybeans; Extr-Sorg = extruded sorghum, soybean meal and soybean oil; Extr-Soy + Sorg = extruded sorghum and extruded soybeans. Treatments for Hancock et al. were: Control = ground sorghum, soybean meal and soybean oil; Extruded Sorg+SBM = sorghum, soybean meal and soybean oil blended and extruded; Extruded+Blended = extrusion of sorghum and soybeans before blending; Blended+Extruded = extrusion of sorghum and extruded soybeans after blending.

Figure 2. Energy Required to Roller Mill Corn is Two to Four Times Greater than that Needed to Roller Mill Sorghum to Particle Sizes from 900 to 500 Microns. The same trend was observed when fine-grinding (1/16" screen) in a hammermill. (Adapted from Healy et al., 1991.)



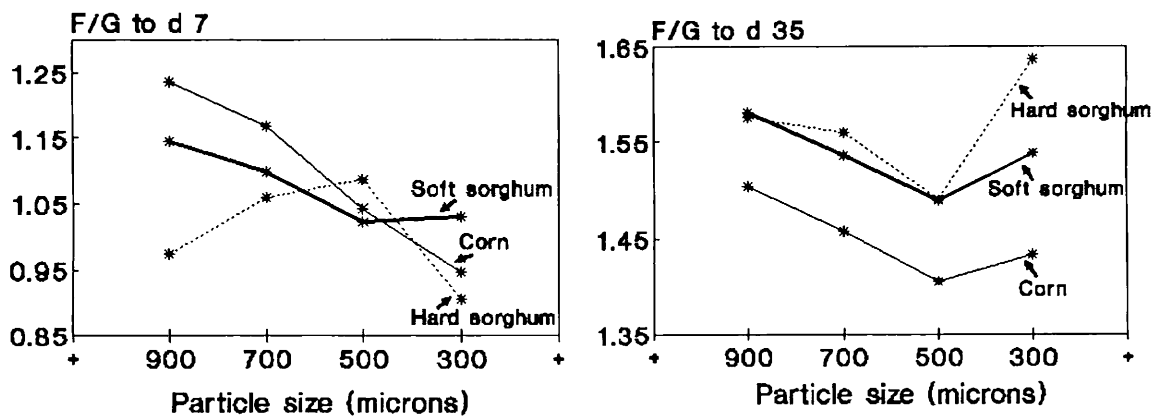


Figure 3. Optimum Particle Size of Cereal Grains Differs with Age of Weanling Pigs and Grain Source. (Adapted from Healy et al., 1991.)