Effects of Processing and Genetics on the Nutritional Value of Sorghum in Chicks and Pigs - Review -

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ABSTRACT : Differences in the physical structure and chemical composition of sorghums result in different nutritional values. Sorghums with high *in vitro* nutrient digestibility tend to have greater ileal and total tract nutrient digestibilies. Soft endosperm can improve growth and nutrient digestibility in nursery pigs and broiler chicks. However, finishing pigs respond less to endosperm hardness. Chicks benefit from waxy sorghums, but responses of swine to waxy sorghum remain controversial. Reduction of particle size benefits nursery pigs more than finishing pigs, while age of chicks affects the coarseness preference. Nutritional benefits of thermal processing in sorghum remain unclear in chicks and pigs. Although experiments have demonstrated increased efficiency with processed sorghum, processing provided only an immediate solution to the problem of reduced utilization. Long-term, solutions will be genetic improvement of physical and on chemical characteristic. (*Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 9 : 1337-1344)*

Key Words : Processing, Genetics, Sorghum, Chicks, Pigs

INTRODUCTION

Sorghum (*Sorghum bicolor, L.,* Moench) is grown extensively in the Great Plains of the United States, Africa, India, Argentina, and other areas with similar dry and climatic conditions. Annual rainfall in these areas ranges from 35 to 60 cm (William et al., 1990). Approximately 48% of the worlds sorghum production is used for animal feeding. Of that, 70% is used by the United States, Mexico, and Japan (FAO, 1995). Sorghum commonly is substituted for corn in diets for swine and poultry, although sorghum has been viewed as having between 90 to 95% of the relative feeding value of corn in swine (Cousins, 1979) and chicks (Hulan and Proudfoot, 1982). For centuries, selections has been based on traits such as milling ease and yield enhancing characteristics (i.e., resistant to disease, drought, and insects). Little emphasis has been given to development of sorghums superior for utilization as nutrients sources for livestock. Research has demonstrated that some physical and chemical traits may be related to nutritional value of sorghum, and genetically controlling these traits would provide potential for improved feeding value in the future.

GENERAL CHARACTERISTICS OF SORGHUMS

Chemical and physical structure

The sorghum grain kernel is approximately 70% starches and sugars, 10% proteins, 3% lipids, 7% mineral and vitamins, and 10% moisture (William et al., 1990; NRC, 1998). These nutrients are distributed as 6% bran, 10% germ, and 84% endosperm (Rooney and Miller, 1982).

The outer coat of the kernal is known as the pericarp, which has three layers (the epicarp, the mesocarp, and the endocarp from outside to inside). The endocarp is located next to the first layer of the endosperm (the aleurone layer) which is composed primarily of lipid, minerals, enzymes, water soluble vitamins and some starch and proteins. Right below the aleurone layer is the endosperm, where most of the starch is stored. However, starch in peripheral endosperm is considered less available because the high protein content in this layer forms a starch-protein matrix (Hoseney, 1994). The floury layer is divided into two structural regions: vitreous and opaque. Starch in the vitreous region is more ordered and linked to a well-defined protein matrix. The opaque region, on the other hand, has a less defined protein matrix and the starch exists more freely in granule type structures that have open areas between the granules (Rooney and Miller, 1982). Inside the endosperm, the germ stores most of the oil, however, the germ of sorghum is embedded deeply and hard to be separated.

GENETICS AND BREEDING

Color : Sorghums with a true yellow endosperm has high levels of carotenoid pigments and the genes affecting carotenoid content are homozygous (Ellis, 1975). The R-Y- genes determine whether the pericarp is genetically red (R-Y-), colorless (R-yy), white (rryy), or lemon yellow (rrY-). There is no association between pericarp color and endosperm color (Rooneyand Miller, 1982).

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Tannin : Brown pericarp sorghums are associated with the presence of a testa layer, which is controlled by the complementary B_1 and B_2 genes. When both are present in the dominant condition, a testa is present. In combination with the dominant spreader gene S-, a brown color to the pericarp results. The testa layer is found beneath the cross and tube cells in the seed of some sorghum genotypes. The presence or absence of the testa is important in determining the nutritional quality of grain sorghum because a large portion of tannins, polyphenolic compounds, are found in the testa layer (Blakely et al., 1979). Chibber et al. (1978) suggested that tannins associate strongly with the kafirin (particularly the cross-linked kafirin) protein fraction of the seed. Because of the nature of this tannin-kafirin complex, the solubility of the protein is greatly reduced.

Starch type : Endosperm characteristics are grouped into two general divisions, endosperm type and texture (Ellis, 1975). Sullins and Rooney (1975) reported that non-waxy sorghum had small starch granules embedded in a dense proteinaceous matrix. The peripheral endosperm of waxy sorghum was less dense and contained larger starch granules. Lichtenwalner et al. (1978) found the dominant expression of the W gene results in a normal endosperm type (WxWxWx) with a 25:75 ratio of amylose and amylopectin. Amylose is very susceptible to digestion by amylase. However, amylopectin is a branched chain starch, with highly ordered structure, and is resistant to water penetration and enzymatic digestion (Rooney and Plugfelder, 1986). The recessive form of the gene expression results in a waxy endosperm type (wxwxwx) with 0:100 ratio of amylose: amylopectin.

Camire et al. (1990) noted that amylose may bind with amylopectin through hydrogen bonding, as well as bind with lipid to form a crystalline structure. These hydrogen bonds and amylose-lipid complexes will restrict swelling and water uptake by the starch granule. Thus, waxy sorghum without amylose will swell more and absorb more water (Subramanian et al., 1982).

Protein : Of the protein content of the endosperm, albumins and globulins account for 2%, glutelins 12%, and the prolamins 76% (Traylor et al., 1984). Hamaker et al. (1995) found kafirin content to be 68 to 73% in sorghum grain and 77 to 82% in the sorghum endosperm. The prolamin (or kafirin) is one of four classes of proteins typically found in cereal grains with high proline and glutamic acid content and little lysine. Sastry et al. (1986) noted that these prolamines were bound in the protein matrix formed by glutelins and the presence of this matrix made sorghum a rather poor in protein digestibility.

Texture : Texture refers to the proportion of hard or corneous to soft or floury endosperm and can be controlled genetically (Ellis, 1975). Seckinger and Wolf (1973) reported that corneous and floury cells differ in density and protein content. The protein granules in floury endosperm are not as tightly packed (less dense) and are smaller than those found in corneous endosperm. Corneous cells contain about twice as much protein as floury cells and have fewer soluble proteins and more kafirin proteins than floury endosperm (Cagampang and Kirleis, 1984). Hoseney (1994) noted that the strength of the starch-protein content bond determines, to a large extent, the hardness of the cereal kernel. Mazhar and Chandrasheker (1995) also demonstrated that hard endosperm kernels contained higher concentrations of kafirins than the soft endosperm kernels.

EFFECTS OF GENETICS AND PROCESSING ON *IN VITRO* DIGESTIBILITY

Endosperm color and tannin content

The lack of information linking pericarp color to chemical composition makes the importance of sorghum color questionable. Thus, caution should be exercised when interpreting research results from experiments investigating the effects of seed color on nutritional value of sorghum (Healy, 1992).

As for endosperm color, Hibberd et al. (1978) noted that *in vitro* DM disappearance and gas production of white and heteroyellow endosperm sorghums were not different. Hibberd et al. (1980) reported that *in vitro* DM disappearance between white, hetero-yellow, and yellow endosperm sorghums were not different.

Kofoid et al. (1978) noted that sorghums with testa had less *in vitro* DM disappearance and ME than non-testa sorghums. Schaffert et al. (1974) indicated that 62% of the difference in *in vitro* DM disappearance between low and high tannin sorghums could be attributed to an indigestible tannin-protein complex.

Starch type

Lamar (1973) reported that starch from waxy sorghum was more rapidly digested *in vitro* by glucoamylase than normal sorghum. Using microscopy, Sullins and Rooney (1974) explained waxy endosperm might be more digestible because of the structure of the endosperm. The waxy endosperm sorghum had a smaller proportion of peripheral endosperm in the kernel than did the non-waxy type. Ellis (1975) also illustrated that dosage of the waxy gene affects the chemical properties and *in vitro* digestibility of sorghum endosperm. A homozygous-waxy genotype produced greater amounts of CO_2 gas during a 48-hour fermentation compared to a normal genotype.

Lichtenwalner et al. (1978) found that increasing waxiness increased starch hydrolysis and *in vitro* DM digestibility for both whole grain and isolated starch. Elmalik et al. (1986) noted that rats fed waxy sorghum had N digestibility similar to that of rats fed corn or pearl millet. In addition, *in vitro* pepsin digestibility demonstrated that waxy sorghum had more digestible protein than normal sorghum. However, Lauver (1988) suggested no correlation between *in vitro* protein digestibility and starch type.

Froetchner (1997) noted that sorghum with waxy endosperm require more energy to process during steam flaking compared to normal and heterowaxy sorghum. But, heterowaxy sorghum had greater *in vitro* gas production after steam flaking than normal and waxy sorghums.

Endosperm texture

Lauver (1988) suggested no correlation between *in vitro* protein digestibility and endosperm texture in sorghums. Weaver (1995) noted that protein bodies in normal sorghum were regularly shaped with a smooth surface while those from a highly digestible soft endosperm cultivar (P851171) were irregularly shaped with deep invaginations. It is currently thought that the high cystein content of the b and r kafirins allows for the formation of intermolecular disulfide bonds which, in normal sorghum cultivars, partially inhibit access of digestible enzymes to the protein bodies. In contrast, the deep invaginations in protein bodies of highly digestible sorghum varieties result in a much greater surface area.

Processing

Starch granules in cereal grains undergo gelatinization during thermal processing. Under the conditions heat and of excess water, the hydrogen bonds in the less ordered amorphous regions of granules are disrupted, which allows water to associate with free hydroxyl groups resulting in swelling. This swelling opens the granules to further impact from water. Melting of the crystalline fraction occurs next and results in complete loss of birefringence (Camire et al., 1990).

Osman et al. (1966) reported that steam flaking increased starch digestion of sorghum by 173% when compared to untreated sorghum and digestion was increased with increased flake thinness. Frederick et al. (1968) also found that *in vitro* starch digestibility increased with increased flake thinness. Neuhaus and Totusek (1969) indicated that the combination of moisture and high temperature increased digestibility of sorghum. Trei et al. (1970) noted that gas production was highly correlated (r=0.95) with DM disappearance and flake thinness. Sullins and Rooney (1974) used microscopic analyses and found the structure of the endosperm in reconstituted grain was modified, releasing a larger portion of the starch and protein. Rolling or grinding the reconstituted grain caused more complete breakdown of the endosperm.

McNeill et al. (1975) conducted experiments to determine the effects of dry ground, steam-flaked, reconstituted, and micronized sorghum grain on *in vitro* digestibility. The starch granules of micronized and steam-flaked grains were completely gelatinized and extensively swelled. However, dry ground and reconstituted grain did not show significant loss of starch granule birefringence. Starch in steam-flaked grain was the most susceptible to alpha-amylase. They concluded that processing methods that increase solubility of the protein matrix encapsulating starch granules in the endosperm, offer promise for increasing carbohydrate utilization.

Mercier and Feillet (1975) adjusted the moisture content of corn starch to 22% and measured the effects of extrusion temperatures from 70 to 225℃. They found that maximum expansion was achieved at 170 to 200℃ with *in vitro* α-amylase digestibility improved from 18% for raw starch to 80% for extruded starch. Starch digestibility was lower for reconstituted (to 30% of moisture, stored for 21 d, then rolled), steam flaked, and dry-roasted-steam-flaked grain than for dry-ground grain. However, Xiong et al. (1990 a,b) reported improved *in vitro* starch availability and protein degradation in steam-flaked and reconstituted sorghum grain.

In vitro protein digestibility was drastically reduced by high temperature, dry toasting when compared to grinding (Lamar, 1973). Axtell et al. (1981) noted that *in vitro* pepsin digestion of uncooked sorghum ranged from 89 to 93% and decreased to 45 to 57% upon cooking. Hamaker et al. (1987) indicated that sorghum proteins develop enzyme-resistant, disulfide bond upon cooking and other cereals apparently do not. However, Fapojuwo et al. (1987) reported that *in vitro* protein digestibility of sorghum grain improved from 45% for ground grain to 73% for extruded grain.

EFFECTS OF SORGHUM GENETICS AND PROCESSING IN PIGS

Effects of genetic differences

Noland et al. (1977) noted that nursery pigs better utilized sorghums with yellow pericarp than sorghums with brown pericarp, but the latter had high tannin content. Simple correlation coefficients were -0.68 and -0.58 between tannin content and digestible energy and digestible protein, respectively. Grabouski et al. (1987) compared sorghums with different pericarp color (bronze, cream, and yellow). In nursery pigs, yellow or cream colored sorghums supported 3% greater ADG and 2% greater G/F than the sorghum with bronze pericarp color. In finishing pigs, yellow and cream colored sorghums supported 1% lower ADG and 3% lower gain/feed than bronze sorghum. It is unclear what caused the inconsistent response in nursery vs. finishing pigs.

Tanksley (1974) evaluated sorghums with white, hetero-yellow, and yellow endosperm for growing-finishing pigs. He found no difference in rate of gain, feed efficiency, and carcass traits among pigs fed the different sorghum grains. However, nutrient digestibility was greater for pigs fed the sorghum with hetero-yellow endosperm. Noland et al. (1977) also noted that a positive relationship exists between yellow pigment in the endosperm and nutritional value in pigs. However, it is most difficult to rationalize why digestive enzymes might prefer endosperm with yellow pigmentation. More probably, early experiments that reported differences among sorghums with different endosperm color actually may have been comparisons of differences in endosperm type and texture. More work is needed to address the relations among endosperm color and endosperm texture and type.

Cousins et al. (1981) reported decreased N and amino acid digestibility at the terminal ileum for high tannin sorghums when compared with low tannin sorghums. Lizardo et al. (1995) evaluated six sorghum varieties varying in tannin content (1.6, 2.2, 3.1, 4.3, 9.2, and 40.1 g/kg of catechin equivalents) in weanling pigs. No effect of tannins growth performance was observed. However, low tannin diets supported greater total tract digestibility of N and GE than medium and high tannin diets. Ileal energy and N digestibility were depressed by high tannin concentrations (exceeding 2.5 g/kg). Chymotrypsin and lipase activities, measured in the pancreas after slaughter at 56 d of age, were increased and trypsin activity was reduced by increased tannin content in the diet. In the intestinal mucosa, the activity of maltase was adversely affected by the presence of tannins but peptidase activity was unchanged. They concluded that the lower activities of proteolytic enzymes in the pancreas and brush border could explain the lower ileal and total tract digestibilities of N.

Cohen and Tanksley (1973) reported no significant difference in protein or crude fiber digestibility among sorghums with floury, intermediate, and corneous endosperm textures. But, there was greater GE and DM digestibility for pigs fed an intermediate texture endosperm sorghum compared to corneous or floury endosperm sorghums. Axtell et al. (1981) reported that softer endosperm tended to improve growth performance and nutrient digestibility in pigs. Healy (1992) noted that nursery pigs fed soft sorghum tended to have greater ADG and gain/feed than pigs fed hard sorghum. Cabrera (1994) reported that finishing pigs fed hard sorghum grew faster but pigs fed soft sorghum were more efficient.

Cohen and Tanksley (1973) reported that pigs fed normal sorghum had numerically higher protein digestibility than those given waxy sorghum. However, Myer and Gorbet (1983) found no difference in growth in pigs fed normal vs. waxy sorghum. Senne (1997) found that pigs fed the normal sorghum had greater ADG while increased dosage of the waxy gene increased N digestibility. Froetschner (1997) reported improved pellet quality with increasing dose of the waxy gene, grinding characteristics were not affected.

Effects of processing

Cereals can be processed in the cold state by cracking, crushing, and grinding to change there physical form (i.e., particle size). Aubel (1945, 1955, 1960) conducted a number of experiments and found that finishing pigs fed ground sorghum were more efficient than pigs fed whole sorghum. ADG of pigs receiving ground sorghum was 12% greater than for pigs fed whole corn.

Koch and Deyoe (1964) evaluated the performance of pigs fed whole grain, dry rolled grain, dry rolled and pelleted grain, steam rolled grain, steam conditioned-rolled grain, and fine ground grain. ADG of pigs was not affected by the grain preparations. Jensen et al. (1965) noted that fineness of ground sorghum in pelleted diets had no effect on ADG and gain/feed.

Beames (1969) compared the digestibility of whole sorghum grain and dry-rolled sorghum grain when using *ad libitum* and restricted feeding for growing pigs. With restricted feeding, digestibility of nitrogen, organic matter, nitrogen-free-extract, and crude fiber was greater. Luce et al. (1970) conducted two experiments to compare the effect of four particle sizes (3.2, 4.8, and 6.4 mm hammermill screens and coarse rolling). Pigs fed the 3.2 mm ground sorghum had greater efficiency of gain than pigs fed 4.8 and 6.4 mm ground sorghums. No differences were observed with ADG and backfat thickness. They concluded that reductions in particle size by grinding will improve feed efficiency but not daily gain.

Owsley et al. (1981) investigated the effect of three particle sizes of sorghum on nutrient digestibility in growing pigs. A coarse particle size was obtained by dry rolling, while medium (6.4 mm screen) and fine (3.2 mm screen) particle sizes were obtained by grinding through a hammermill. Reducing particle size improved digestibility of DM, starch, GE, N, and most amino acids. Ohh et al. (1983) noted greater digestibility of DM, N, and GE as screen size was decreased from 6.4 mm to 3.2 mm. They concluded that increased surface area and increased mixing of digesta with intestinal secretions may account for the improvement in digestibility. Wu (1984) indicated that decreasing particle size of sorghum from 1,125 to 700 microns tended to improve feed efficiency in finishing pigs but not in nursery pigs. The digestibility of dry matter, N, and GE of grain sorghum was improved as particle size was decreased for finishing pigs but not for nursery pigs. Giesemann et al. (1990) reported that fine grinding improved efficiency of gain and digestibility of DM and N in finishing pigs fed yellow sorghum.

Healy (1992) reported that as particle size was reduced, production rate decreased and energy required to mill increased. But, efficiency of gain was greatest at 500 micron for both hard and soft sorghum. Cabrera (1994) indicated that gain/feed of finishing pigs increased linearly with decreased particle size, but the incidence and severity of gastric lesions also increased. Nutrient digestibility increased with decreased particle size with a maximum at 400 microns for both hard and soft endosperm sorghums. The author concluded that the optimal particle size for finishing pigs is less than 600 microns.

Aubel (1959) evaluated whole, rolled, and steam-rolled sorghums in growing-finishing pigs. No treatment effect was observed. In another study, Aubel (1960) compared whole, rolled, steam-rolled and steam conditioned sorghums. He found pigs receiving the steam-rolled grain and dry-rolled grain gained at approximately the same rate. Pigs fed whole grain had the poorest gains. Allee (1976) found little difference when extruded sorghum was fed to young pigs. However, Noland et al. (1977) reported that extrusion improved energy and N digestibility of sorghum grain when fed to nursery pigs. William et al. (1990) concluded in a review that steam conditioning, flaking, and other processing methods have no advantage over grinding of sorghum grain for swine. However, Hancock et al. (1991a) reported improvements in efficiency of growth and nutrient digestibility when extruded sorghum was fed to finishing pigs. Hancock et al. (1991b) indicated improved efficiency of gain and nutrient digestibility when ground sorghum, SBM, and soy oil were blended and extruded together. Mills (1994) reported that an extruded sorghum and soybean blend improved digestibility of nutrients and sow performance, but also increased the incidence of stomach ulcers compared to a ground-sorghum control. Johnston et al. (1998) noted that lower litter weight gains in sows fed sorghum-based vs. corn-based diets. However, those differences vanished when the diets were expanded and pelleted. Traylor et al. (1998) found that sorghum-based diets required less energy input to expand and had equal to slightly greater energy value than expanded corn-based diets.

EFFECT OF SORGHUM GENETICS AND PROCESSING IN CHICKS

Effects of genetic difference

Richert et al. (1991) reported that bronze pericarp sorghum had 5% more MEn, but chicks fed yellow sorghum were 4% greater in efficiency of protein utilization. Less information is available on evaluation of the nutritional value of endosperm color in chicks.

Nelson et al. (1975) reported negative relationships among tannin content and digestiblity of DM, N, and energy. Douglas et al. (1990a) noted that ME was not different for corn and low-tannin sorghums in chicks. Gualtieri and Rapaccini (1990) summarized feeding trials with broilers and suggested that low tannin sorghum diets (<1.0%) can replace isonitrogenous corn-based diets in chicks with equivalent growth performance. Douglas et al. (1990b) reported that chicks fed low-tannin sorghum supported greater rate and efficiency of gain than high tannin sorghum. Longstaff and McNab (1991) noted that condensed tannins in sorghum can inhibit digestive enzymes.

Healy (1992) reported hard sorghum had greater DM and N digestibility than soft sorghum. However, interactions existed among sorghum endosperm hardness and particle size. ADG was maximum at 700 microns for hard sorghum and 500 microns for soft sorghum. However, gain/feed was maximum at 300 microns for hard sorghum, and 500 microns for the soft sorghum. Cabrera (1994) reported that soft sorghum required less energy to grind than hard sorghum. However, there was no difference in growth performance of chicks fed sorghum with hard or soft endosperm.

Effects of processing

Eley and Hoffmann (1949) reported that when diets were ground to 1/2, 4/16, 13/65 and 3/32 inch mesh and fed to 6-wk old chicks, water consumption and excretion increased as particle size increased. Zhuge et al. (1990) used sorghum in chick diets after grinding to particle sizes of 312 or 1,196 microns. Particle size did not affect chick performance in 5 wk. Cabrera (1994) reported that the nutritional value of simple diets for broiler chicks was increased by crumbling and particle size reduction (1,000 to 500 microns). However, in complex diets fed as crumbles, reducing particle size (1,000, 800, 600, and 400 microns) did not improve growth performance. Healy (1992) reported that sorghums with high *in vitro* digestibility were of greater nutritional value to chicks. As particle size was reduced, efficiency of gain was improved. When compared at their optimal particle sizes, chicks fed sorghums had equal performance to those fed corn.

Nir and Hillel (1994) ground sorghum to three particle sizes and found the best performance with diets in medium particle size (1.13 to 1.23 mm); the fine fraction (0.57 to 0.67 mm) resulted in the lowest performance. Gizzard weights at d 7 and 21 were positively correlated to particle size. The pH of the gizzard contents decreased and small intestine contents increased with increasing grain particle size. Nir et al. (1990) noted that chicks consumed feed in accordance to its coarseness and ADG was positively related to the coarseness of feed.

Boldaji (1969) and Weber et al. (1969) found that steam flaking increased the metabolism energy for sorghum grain in poultry. Deyoe et al. (1967) reported that broilers fed expanded sorghum had lower growth performance than those fed non-expanded grain. Sloan et al. (1971) found little difference in ADG (2%) and efficiency (6%) when extruded corn or sorghum replaced ground grains in diets for broiler chicks. Mitaru et al. (1983) reported that chicks fed diets with reconstituted sorghum grains had improved weight gains and feed efficiencies.

Zhuge et al. (1990) used sorghum ground through a hammer mill, a roller mill, extruded and steam-flaked. For ADG, the treatments were ranked coarse rolled > coarse hammer milled > extruded > finely rolled > finely hammer milled > low density steam-flaked > high density steam flaked.

Reece et al. (1984) reported that crumbling improved gain/feed of chicks at d 21. Choi et al. (1986) found chicks fed a crumbled starter diet had decreased gizzard wt at 4 weeks of age. Pelleting the finisher diet also reduced weight of the digestive tract and gizzard at 8 weeks of age, compared those fed mash diet. However, Nir et al. (1995) found that crumbling and pelleting improved growth performance compared to a mash diet. Douglas et al. (1990b) noted sorghums in pelleted diets improved weight gain and feed efficiency.

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