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Screening grain sorghums for bird tolerance and nutritional quality

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A sorghum breeding program is described in which the major objective was to develop tannin-containing group II sorghums that resist bird damage in the early stages of grain development, and then ripen into palatable grain of high nutritional quality. In the bird-resistance screening nursery, group II, standard group I, and standard group III sorghum entries exposed to high levels of bird-feeding pressure, were assessed for bird damage and content of protein binding (i.e. active) tannins at 21 days after half-anthesis (DAHA), and at physiological maturity. Although several group II entries were equivalent to group III (brown sorghums) standards in bird resistance and active tannin content at 21 DAHA, none had measurable active tannins in the mature grain. These observations were corroborated by nutritional studies. Sixteen group II entries with bird tolerance and agronomic desirability were tested for nutritional quality in rat feeding studies. Four group II entries were nutritionally equivalent to the group I (non-tannin) standard line. Seven entries equalled the group III (nutritionally deleterious) standards in feeding value. Although classic tannin effects were observed in some sorghum varieties, it appeared that non-tannin chemical effects were affecting feeding by birds in others. A group I (non-tannin) sorghum was almost avoided.

Keywords: sorghum; birds; tannins; nutrition; bird damage; tolerance

Condensed tannins have been recognized as one of the better chemical means of protecting ripening sorghum grain from bird damage. Until the late 1960s, genotypes with a testa were recognized as tannin-containing and synonymously called 'brown' or bird-resistant (BR) sorghums. These varieties were favored in areas where bird depredation was a problem (Harris, 1969; Tipton *et al.*, 1970; McMillian *et al.*, 1972). Their use diminished as animal nutritionists recognized that mature grain from these sorghums had both low palatability and digestibility (Chang and Fuller, 1964; Harris, 1969; McGinty, 1969) causing reduced market value.

Thus, depending upon one's focus on the outcome, both BR efficacy and antinutritional properties have become virtually synonymous with 'tannin effects' of brown sorghums. The tannin effects or 'tannin activity' discussed herein refer to protein binding capacity of condensed tannins of the sorghum grain. Active tannin oligomers bind with mucoproteins in the mouth causing an astringent tactile response that is repellent to birds (Bullard *et al.*, 1980). Likewise, protein binding causes antinutritional effects through inhibition of digestion, metabolism, and assimilation processes (Butler, 1989a). An inverse relationship has been reported between tannin activity, and both bird avoidance (Bullard *et al.*, 1980, 1981) and grain-feeding value (Chang and Fuller, 1964; Harris, 1969).

As research on tannin-containing sorghums continued through the 1970s and early 1980s, scientists were beginning to recognize a large divergence in the sorghums' polyphenolic properties (Cummings and Axtel, 1973; Price *et al.*, 1979; Bullard *et al.*, 1980, 1981). It appeared that hybrids could be developed that would resist damage in the milk and dough stages, when bird damage is highest (Hoshino and Duncan, 1982; Bullard and Gebrekidan, 1989), and then ripen into nutritionally acceptable grain. Scientists at Purdue University, USA reported tannin-containing genotypes that produced grain equivalent in nutritional quality to non-tannin sorghums (Cummings and Axtel, 1973; Oswalt, 1975; Hartigan, 1979). To classify this genotype (called group II), they subsequently developed a grain sorghum classification system based on tannin extraction characteristics (Cummings and Axtel, 1973; Price *et al.*, 1978; Asquith *et al.*, 1983) as follows: (1) group I sorghums that do not contain a testa and therefore no tannin; (2) group II sorghums with a testa and tannin, but during ripening, biochemical processes occur whereby tannin can no longer be extracted with methanol; and (3) testa-containing group III soghums that, after ripening, have varying concentrations of tannin that are extractable with methanol.

Group II sorghums have not generated much interest because lines with sufficient tannin activity in the immature stage to deter granivorous birds are difficult to find (Bullard and Elias, 1980; Butler, 1982a).

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However, collaborative studies between the Denver Wildlife Research Center and University of Arkansas Agronomy Department included some group II purple-testa genotypes that had higher tannin activity in the immature stages than had been previously observed (York *et al.*, 1981, 1983). We, therefore, began a sorghum varietal screening program based on the above classification system, a protein precipitation test, a bird damage assay and a rat feeding study.

Materials and methods

Our objective was to compare the effects of protein-binding activity of tannins in the early and late stages of grain development. Bird damage and tannin activity were both assessed at 21 DAHA (the early dough stage) and physiological maturity. As plots were evaluated for bird damage, grain samples were collected for an evaluation of protein (bovine serum albumin or BSA) binding/precipitation capacity of the respective methanol extracts. Because group II sorghum grain was reported to not be nutritionally deleterious (Oswalt, 1975; York *et al.*, 1983) and tannin from it to not be extractable with methanol (Price *et al.*, 1978), it was assumed that methanol would extract only active BSA-binding tannins.

Annual bird damage study

Annually, 36 sorghum-inbred lines or hybrids were planted in a bird evaluation test on a Captina silt loam soil at the Agronomy Farm of the University of Arkansas, Fayetteville, USA. The sorghums were planted in one-row plots and replicated six times in a triple lattice design. Seeds were planted 500 per 15.2 m row, with row widths of 1 m. The fields were fertilized before planting with a mixture containing 44.8 kg ha^{-1} each of N, K_2O, and P_2O_5 and side-dressed with 89.6 kg ha^{-1} of N when the plants were about 25 cm tall. The crop received 3.8 cm of water every 10 days, either by rain or furrow irrigations, from 1 June until 31 August.

The flowering dates of panicles from each sorghum test plot were recorded, and at 21 DAHA, three heads were collected for protein precipitation analysis. To avoid biochemical changes caused by sample handling (Price *et al.*, 1979), panicles were cut with 15 cm peduncles, carried to the edge of the field, and frozen by dipping them in liquid nitrogen. They were then packed under dry ice, transported to the laboratory, and stored at −20°C. Later, they were lyophilized and hand-threshed with a series of sieves to obtain clean, immature seeds. The seeds were then ground 2- to 20-mesh with a Wiley mill and stored at −20°C until analysis. Mature samples were collected at maturity (54 DAHA), ground to 20-mesh, and also stored at −20°C.

Every summer, there had been high populations of resident redwinged blackbirds (*Ageliaus phoeniceus*) and brown-headed cowbirds (*Molothrus ater*) at the test site. The bird damage assay was conducted by two individuals on the dates when the last test sorghums had reached 21 DAHA and physiological maturity (colored grain and at 22% moisture). Each investigator visually examined and ranked a test row for bird damage on a scale of 1–9 (where 1 = 0–2%; 2 = 3–10%; 3 = 11–20%; 4 = 21–35%; 5 = 36–64%; 6 = 65–79%; 7 = 80–89%; 8 = 90–97% 9 = 98–100% bird damage). The added weighting toward very small and nearly total damage ensured that distinctions between none and a little, and between total and nearly total, would not be lost. Each of the six replications was evaluated on this basis, resulting in a mean rating for the test sorghum. Means were then separated and ranked according to Duncan's Multiple Range Test.

Classification by panicle type

Panicles from each test entry were classified according to one of five head compactness ratings (where 1 = panicle long and slender; 2 = panicle short and oval; 3 = panicle elongated and oval; 4 = panicle elongated and rectangular in shape; and 5 = panicle open and elongated).

Protein participation assay

All samples were analyzed for protein precipitating capacity as described by Hagerman and Butler (1978), with the addition of a methanol wash of the protein-tannin precipitate (Bullard *et al.*, 1981) and a small change in the extraction procedure. Briefly, ground sample (0.5 g) was extracted with 5 ml of absolute methanol for one hour at 22°C on a platform shaker. One milliliter of extract was mixed with 1 ml of 1.0 mg/ml bovine serum albumin (Sigma Fraction V) in 0.2 M acetate buffer (pH = 5.0). After 15 min, the mixture was centrifuged at 6500 rpm for 10 min, and the supernatant was discarded. The protein–tannin pellet was then washed (twice) with absolute methanol by gently breaking up the pellet and centrifuging it. The purified pellet was dissolved in 4 ml of sodium dodecyl sulfate (SDS)–triethanolamine solution (1% SDS and 5% (v/v) triethanolamine, in distilled water). Then, 0.01 M ferric chloride (in 0.01 N HCl) solution was added and approximately 15 min later the absorbance was read at 510 nm on a UV/Vis spectrophotometer standardized with purified BR-54 tannin (Hagerman and Butler, 1978).

Rat feeding studies

Male weanling Sprague-Dawley rats (Simonsen Laboratories, Gilroy, CA) that were 21 days old and weighed 50–60 g, were fed Purina Laboratory Rodent Chow for a 7 day acclimation period. Test rats were randomly divided into groups of six each and then housed individually in 24 × 20 × 18 cm wire-bottomed stainless steel cages. A catch-pan was located under each cage to collect spilled food and droppings as appropriate. The test diets and water were provided *ad libitum* for 28 days. Rats were weighed every 7 days and food consumption was recorded as additional diet was supplied. At the end of 28 days, total weight gain and food consumption were determined for each diet. Diets were compared using one-way analysis of variance (ANOVA), and means were separated by Tukey's mean separation test (Tukey, 1977). Linear regression comparisons were made among certain variables.

In each study, sorghum grain was the main dietary constituent. All sorghums used in a diet were analyzed for protein, fat, fiber, ash and moisture contents by standard proximate analysis. Each diet contained the same quantity of a sorghum grain, and based on proximate analysis values it was formulated to contain 10% protein (with either casein or corn starch), 5% total fat (with corn oil), 5% crude fiber (with carboxy methyl cellulose), 5% AINS mineral mix, and 1% AINS vitamin mix. The selection of these dietary criteria is similar to other studies of tannin effects in rat diets (Jambunathan and Mertz, 1973; Schaffert *et al.*, 1974; Featherstone and Rogler, 1975).

Sorghum grain that had been held in storage for no longer than 4 months and at temperatures lower than 22°C was freshly ground and mixed with other diet constituents a day before test intiation. Each formulated diet was analyzed for protein (BSA) binding activity.

Results and discussion

The results of the 1988 test are presented as being representative of a typical test season (*Table 1*). The damage ratings and percent tannin values are listed (*Table 2*) for five standard/control sorghum entries used in screening tests from 1985 through 1988. In both examples, the tannin-containing sorghums consistently sustained low damage in both rating indices than did group I varieties. The close agreement in data from replicate entries of Tx 2790 × IS8100c (*Table 1*) is an indicator of method precision within a given year.

We observed that nine of the 10 group IIIs and 10 of the 18 group IIs had less than 3% bird damage at 21 DAHA (*Table 1*). At physiological maturity, the values were 7% and 4%, respectively. Of the group II and III entries, only KS56 × AR3011 had more than 10% damage at 21 DAHA, and by physiological maturity, only four group IIs reached that level. Seven group IIs had less damage than standard TAM 2566DW$_3$, at 21 DAHA, and one group II (IS8100c) had less damage at physiological maturity. Three group II sorghums (Ark 2043, Ark 2062, and KS57 × AR3011) had tannin levels at 21 DAHA equal to or greater than either AR3003 × Tx 430 or Funks G-1516BR, thus satisfying one major initial objective. All of the group IIIs had 0.17% or more tannin in the ripened grain, but only one group II (Ark 2097) had detectable levels (0.04%)

Table 1. Sorghum bird resistance nursery, main experiment station, Fayetteville, Arkansas (1988)

Entry	Sorghum group*	Bird damage rating†		Percent tannin‡		Panicle type§
		21 DAHA	Maturity	21 DAHA	Maturity	
Tx 399 × Tx 430 (std.)	I	7.1 a	7.7 b–d	ND	ND	4
AR3304 × Ark 1097	I	7.0 a	8.5 a–b	ND	ND	3
Ark 1097	I	3.0 b–c	5.5 c	ND	ND	2
Ark 2034	I	3.2 b	6.6 d–e	ND	ND	4
Ord G Xtra	I	7.8 a	7.9 a–c	ND	ND	4
Tx 77CS8397	I	7.7 a	9.0 a	ND	ND	3
Tx 2790 × Ark 1097	I	6.8 a	7.1 c–d	ND	ND	3
TAM2566DW$_3$ (std)	II	2.4 b–c	3.5 f–i	0.11	ND	2
Ark 1001-1	II	1.4 c–j	1.8 h–m	ND	ND	3
Ark 2013	II	2.1 b–i	3.1 f–h	0.04	ND	4
Ark 2019	II	2.4 b–g	3.5 f–g	0.11	ND	4
Ark 2032	II	1.6 e–j	2.4 f–l	0.28	ND	3
Ark 2033	II	1.9 c–j	2.2 g–m	0.11	ND	4
Ark 2038	II	2.4 b–f	2.9 f–j	ND	ND	5
Ark 2041	II	1.0 i–j	1.9 h–m	ND	ND	3
Ark 2043	II	1.4 e–j	2.1 h–m	0.71	ND	3
Ark 2046	II	2.2 b–h	2.5 f–l	ND	ND	4
Ark 2051	II	1.9 c–j	2.4 f–l	ND	ND	3
Ark 2062	II	1.0 i–j	2.7 f–k	1.23	ND	5
Ark 2079	II	1.7 d–j	2.0 h–m	0.54	ND	4
Ark 2097	II	2.4 b–g	2.3 f–m	ND	0.04	4
IS8100c	II	1.1 h–j	1.4 k–m	0.50	ND	5
KS57 × AR3009	II	2.7 b–d	2.8 f–k	ND	ND	3
KS57 × AR3011	II	1.0 j	1.8 h–m	0.84	ND	5
KS57 × Ark 2014	II	2.7 b–d	3.0 f–i	0.05	ND	4
AR3003 × Tx 430 (std.)	III	1.3 f–j	1.5 k–m	0.98	0.47	5
Funks G-1516BR (std.)	III	1.4 e–j	1.3 l–m	0.74	0.37	5
Ark 2196	III	1.1 h–j	1.7 i–m	0.23	0.53	5
KS56 × AR 3011	III	3.2 b	3.6 f	0.80	0.17	5
Tx 2761 × AR 3009	III	1.3 f–j	1.2 l–m	1.16	0.43	4
Tx 2761 × AR 3011	III	1.0 i–j	1.6 j–m	0.56	0.39	5
Tx 2761 × Ark 2014	III	1.6 e–j	2.1 h–m	0.45	0.43	4
Tx 2761 × Ark 3040	III	1.0 j	2.0 h–m	0.74	0.56	4
Tx 2790 × Ark 3009	III	1.3 g–j	1.9 h–m	0.61	0.31	3
Tx 2790 × IS8100c	III	1.2 f–j	1.2 l–m	1.49	0.80	4
Tx 2790 × IS8100c	III	1.1 h–j	1.0 m	1.32	0.74	4

*Sorghum tannin classification (Price *et al.*, 1978)
†1 = 0–2%; 2 = 3–10%; 3 = 11–20%; 4 = 21–35%; 5 = 36–64%; 6 = 65–79%; 7 = 80–89%; 8 = 90–97%; 9 = 98–100%
‡Percent tannin by protein precipitation method (Hagerman and Butler, 1978)
§1 = head long and slender; 2 = head short and oval; 3 = head elongated and oval; 4 = head elongated and rectangular; and 5 = head open and elongated
Ratings followed by similar letters are not significantly different at the 0.05 LSD level of probability using Duncan's Multiple Range Test

Table 2. Performance for tannin group standards (4 successive years screening), main experiment station, Fayetteville

Entry	Tannin group*	1985		1986		1987		1988	
		Damage rating†	Percent tannins‡	Damage rating†	Percent tannins‡	Damage rating†	Percent tannins‡	Damage rating†	Percent tannins‡
ORD–XTRA	I	6.0/7.5	ND/ND	7.2/9.0	ND/ND	3.5/6.5	ND/ND	7.8/7.9	ND/ND
Tx 399 × Tx 430	I	5.3/6.9	ND/ND	7.0/8.9	ND/ND	3.5/5.2	ND/ND	7.1/7.7	ND/ND
TAM2566DW$_3$	II	1.8/3.4	ND/ND	1.6/2.8	ND/ND	1.2/2.8	0.03/ND	2.5/3.0	ND/ND
AR3003 × Tx 430	III	1.1/2.1	0.52/1.32	1.7/2.5	1.47/0.97	1.0/2.0	1.84/1.22	1.3/1.5	1.0/0.5
Funks G-1516BR	III	1.0/1.9	2.26/0.99	1.3/2.2	0.96/0.53	1.0/2.0	2.08/0.83	1.4/1.3	0.8/0.4

*Sorghum tannin classification. (Price *et al.*, 1978)
†1 = 0–2%; 2 = 3–10%; 3 = 11–20%; 4 = 21–35%; 5 = 36–64%; 6 = 65–79%; 7 = 80–89%; 8 = 90–97%; 9 = 98–100% @ 21 DAHA/physiological maturity
‡Percent tannin by protein precipitation method (Hagerman and Butler, 1978) @ 21 DAHA/physiological maturity

of tannin. Two of the group Is had about 11% damage and the other five had 80% or more bird damage.

Over the 4 year period, there appeared to be a consistent pattern of tannin deposition influenced by both gene expression and experimental conditions (*Table 2*). At physiological maturity, AR3003 × Tx 430 consistently had higher tannin levels than Funks G-1516BR, but there were reversals at 21 DAHA. During the 2 years (1985 and 1987) when tannin development was highest, Funks G-1516BR had higher tannins at 21 DAHA, while the reverse was true the other 2 years. Shading (Harris, 1969; Mabbayad and Tipton, 1975; Hoshino and Duncan, 1982) and temperature (Hoshino and Duncan, 1982) have been reported to influence the rate of tannin deposition. The mean temperature for the first 21 DAHA for those years (1985 = 77.5°F; 1986 = 76.1°F; 1987 = 82.7°F; 1988 = 82.2°F) obviously did not explain the differences. Varietal differences in tannin formation rates are not uncommon in grain sorghums (Davis and Hosney, 1979; Price *et al.*, 1979; Hoshino and Duncan, 1981; Bullard and Gebrekidan, 1989).

Thus, selecting 21 DAHA for assessing bird damage and tannin concentrations is not without some experimental bias. Much of the tannin biosynthesis and bird-feeding pressure occurs at about this time (Bullard and York, 1985; Bullard and Gebrikidan, 1989), and as indicated above, factors such as genotype, temperature, and sunshine can influence these measurements. With a few exceptions, the damage rating at 21 DAHA was a good indicator of final bird damage. Twenty-one of the 26 varieties having a 2.4 damage rating (about 5% damage) or less at 21 DAHA did not surpass that level at physiological maturity. This pattern was similar over a period of 4 years (*Table 2*).

Morphological differences in test varieties were not sufficient for these factors to have a decisive role in the screening program. Panicle type is considered to be a morphological factor for large birds (Doggett, 1957; Tipton *et al.*, 1970) but probably not in our screening program. At 21 DAHA, all panicles are essentially compact. Bird damage rating at physiological maturity and panicle-type did not correlate for either group III ($r = 0.177$; $P > 0.05$) or group II ($r = -0.1052$; $P > 0.05$) sorghums. In fact, eight group II sorghums had a damage rating of 2.3 or less, none of which had a lax panicle (*Table 1*). Awns and glumes have been reported to influence bird feeding preference (Bullard and York, 1985; Bullard and Gebrekidan, 1989), but all the test sorghums in these studies were awnless, and the glumes seldom cover more than half of the grain.

Seed appearance (color, shape and size) can also influence bird feeding preference, mainly from the standpoint of familiarity (Bullard and York, 1985). Birds generally prefer a familiar food item. However, this effect had not been an important one in these nursery tests in previous years and was not one of the parameters measured. The local flock of birds are annually exposed to a wide diversity of seed appearance among the many cultivars at the University of Arkansas. Most of the testa-containing varieties are a shade of brown-red colour. The six replications with rows planted randomly in a triple lattice design is a good safeguard against minor effects.

In the rat feeding studies, four group II candidates (Ark 2043, Tx 2761 × AR3037, Ark 2092, and Ark 2038) were equivalent to both standard group I varieties (Tx 339 × Tx 430 and DK-41A) in feed consumption, weight gain, and feed efficiency (*Table 3*). All were statistically equivalent, and had better feed efficiency values than standard group II TAM 2566DW$_3$. Seven group IIs equal to standard group III AR3003 × Tx 430, but different from these four varieties and the group I standards, were dropped from future consideration. The coefficients of determination of feed consumption, weight gains, bird damage and percentage tannins were all extremely small, indicating that the variation in percentage tannins for the 16 varieties was too small to account for much of the differences in these three dependent variables. If tannin was the only factor contributing to feed consumption, weight gain, and feed efficiency, all 12 group II varieties would be equivalent to the group I standard varieties.

Additional biochemical factors, not necessarily the same ones in all varieties, seem to be present that produce results that cannot be interpreted solely on the basis of tannin activity. This is consistent with other published studies (McMillian *et al.*, 1972; Mabbayad and Tipton, 1975; Butler, 1982b; Subramanian *et al.*, 1983; York *et al.*, 1983; Butler, 1989a,b; Jimenez-Ramsey *et al.*, 1994). It has been suggested that low molecular weight polyphenols may be at least partially responsible for the toxic effects observed in high tannin sorghums (Butler, 1989a; Jiminez-Ramsey *et al.*, 1994). Perhaps, they may be responsible for bird-repellent effects as well.

Tannin activity for group II sorghums (*Table 1*) did

not correlate negatively ($r = 0.155$; $P > 0.05$) with bird damage rating at 21 DAHA as might be expected. Twelve of the group IIs had less than 0.12% tannin and less than 10% damage at 21 DAHA when bird feeding is high. Four of the eight group II sorghums with a damage rating of 2.3 or less at physiological maturity were low tannin varieties. Some low tannin group IIs consistently performed well in the damage assay (*Table 2*). Birds avoided Group I Ark 1097 in three consecutive years' testing. it had the lowest food consumption and poorest feed efficiency value (*Table 3*) in rat feeding studies.

Thus, because of non-tannin chemical factors that affect bird feeding preference as well as nutritional quality of the ripened grain, one must conclude that the protein precipitation assay may not be a good tool for screening sorghum varieties for either bird resistance or nutritional quality.

Apparently, the differences between condensed tannins in group II and III sorghums lie more in extractability than structural differences. Asquith *et al.* (1983) observed that the types of tannin polymers purified from group II IS8768 were structurally indistinguishable from those purified from sorghum BR 64 (group III). However, group II and residual group III tannins only could be extracted with acidic methanol. While acknowledging that there had not yet been a defensible chemical explanation for the differences in extractability of the tannins from group II and III sorghums, they suggested that the two groups may differ in acid-labile bonding (i.e. glycoside or ester) or structural properties that either affect tannin extractability or limit its accessibility to the solvent. They also noted that tannin in acidic methanol extracts had a higher relative degree of polymerization than that found in methanol extracts. This corroborates earlier speculations that the average polymer size is larger in group II than it is in group III tannins (Bullard *et al.*, 1981), which alone can affect both extractability and protein-binding activity. Goldstein and Swain (1963) observed protein-binding activity to be associated with oligomers containing 3–10 monomeric residues, and above this size, binding decreased as size increased.

Ark 2062 had very high tannin levels and a damage rating of 1 at 21 DAHA, yet it sustained as much as 8% additional damage before physiological maturity (*Table 1*). There are large differences in the rate and process of tannin formation in sorghums (Price *et al.*, 1979; Bullard *et al.*, 1981) and the polymerization process seems to occur more quickly and go farther to completion in group II than it does in group III sorghums (Bullard *et al.*, 1981). Ark 2062 would appear to be an extreme example of this early polymerization process. It was dropped from the screening program because it did not perform as well in the second bird damage rating as other group II sorghums, having lower initial levels of tannin.

One question often raised concerns the relevance of results from a field evaluation of bird damage involving 36 varietal choices to typical field cropping situations where only one sorghum variety is grown. Even the most astringent sorghums will sustain heavy damage if granivorous bird populations are large enough, and there is a shortage of alternative food (Harris, 1969; Farris, 1975; Bullard and York, 1985; Bullard and Gebrekidan, 1989). Beesley and Lee (1979) addressed this problem in screening sorghums and suggested that lines should be tested in isolation before being released to farmers. This has been our plan as well. In addition, any literature for farmers should caution that the performance of a particular bird-tolerant sorghum would be dependent on bird populations in the area and the availability of alternate sources of food.

The advantage of this test design is that feeding behavior is uniform among the test lines. In a previous collaborative study (Denver Wildlife Research Center and Purdue University Biochemisty Department) in Puerto Rico on *Lonchura cuculata* (Bullard and Elias, 1980; Butler 1982a) and in these damage assessments on blackbirds, we have observed uniform patterns in feeding behavior within this test regime. Even though a test sorghum has different neighboring rows in each

Table 3. Consumption and feed utilization efficiency of group II and standard sorghum-based diets fed to Sprague-Dawley rats*

Variety	Group	Percent tannin	Grams feed consumed†	Grams weight gained†	Feed utilization efficiency†‡
Tx 399 × Tx 430 (std)	I	ND	526.7 a	97.0 a b	5.4 a b
DK-41A (std)	I	ND	507.4 a	86.7 a	5.8 a b
Ark 1097	I	ND	324.0 b	25.8 b	12.6 c
Ark 2043	II	ND	581.4 a	105.3 a	5.5 a b
Tx 2761 × AR3037	II	0.07	544.7 a	94.7 a	5.8 a b
Ark 2092	II	ND	516.2 a	84.8 a	6.1 a b
Ark 2038	II	0.04	493.5 a	75.1 a	6.6 a b
TAM 2566DW$_3$ (std)	II	ND	490.5 a	72.2 a	6.8 b
Ark 2047	II	ND	451.5 a b	50.6 b	8.9 c
IS8100c	II	ND	406.9 b	47.2 b	8.6 c
Ark 2115	II	ND	396.4 b	40.2 b	9.9 c
Ark 2017	II	ND	387.8 b	33.3 b	11.6 c
KS57 × AR3037	II	ND	385.0 b	36.3 b	10.6 c
Ark 2051	II	ND	384.9 b	34.9 b	11.0 c
Ark 2075	II	ND	384.0 b	35.6 b	10.8 c
AR3003 × Tx 430 (std)	III	0.28	425.1 a b	47.0 b	9.0 c

*Table values are means ($n = 6$)
†Means followed by the same letters do not differ significantly from each other
‡Feed efficiency value is obtained by the formula:

$$\frac{\text{g feed consumed}}{\text{g weight gained}}$$

replicate, the variation among damage ratings for replicates is generally small (*Table 1*). The important factor in genotype screening is that one is able to rank sorghums according to bird resistance. If standard group I, II, and III sorghums are tested each year for comparison, one can easily make efficacy comparisons. Because of the dependence of tannin deposition on environmental factors discussed above, it is best to make any tannin-based sorghum efficacy comparisons from data collected the same year in which the test was conducted.

In addition to the estimates of bird damage in the nursery test, agronomic data were collected on each of the candidate test sorghums. Factors such as yield, DAHA, plant height and lodging, panicle exertion and compactness were recorded. The most promising sorghums in terms of bird tolerance and agronomic desirability were carried for an extra 2 years. If a sorghum was of interest after 3 years of testing, nutritional studies were conducted. If performance in these studies was satisfactory, then advanced field studies on single varieties were conducted. Based on this breeding program, the University of Arkansas has released group I and II sorghum lines that excel in bird tolerance and have good nutritonal quality. Others are encouraged to join the effort to develop nutritionally acceptable bird-resistant sorghums.

Acknowledgements

J.O. York died on 7 November, 1992. This final paper is dedicated to his memory and to over 15 years of productive, co-operative research between the Department of Agronomy, University of Arkansas and the Denver Wildlife Research Center of the U.S. Department of Agriculture.

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