VARIETAL, ENVIRONMENTAL AND PROCESSING EFFECTS ON THE NUTRITIVE CHARACTERISTICS OF SORGHUM GRAIN

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INTRODUCTION

Sorghum grain is extensively utilized as a concentrated source of energy in almost all phases of livestock production. Currently, about 13 million tons of sorghum grain are fed to livestock each year. Sorghum grain is highly drought tolerant, especially in contrast to other cereal grains such as corn. Consequently, as water shortages grow and the cost of irrigation continues to increase, total sorghum acreage will probably increase, resulting in greater quantities of sorghum grain available for livestock.

Traditionally, sorghum grain has not been a popular feed grain among livestock producers. Poor acceptance or discrimination against sorghum grain is due to at least two factors. First, sorghum grain generally has lower feeding value than other cereal grains, especially corn (Morrison, 1959). Second, sorghum grain is highly variable in kernel characteristics such as seed coat color, berry size or endosperm hardness and in feeding value, due to content and digestibility of protein, starch and tannin (Hibberd, 1979). Much of the variation in sorghum quality is associated with variety or endosperm type. Environmental factors such as moisture level, ambient temperature or nitrogen fertilization during growth and maturation may further influence the ultimate feeding value of the mature grain.

The feeding value of sorghum grain can be enhanced by several grain

processing methods. Recently, energy efficient methods such as reconstitution and high moisture harvest of sorghum grain have received increased attention. Because different varieties of sorghum grain vary in digestibility when mature, the ultimate success of processing may also be variety dependent (Hibberd, 1979).

Recent evidence suggests that the site and extent of energy and protein digestion can be substantially altered by different grain processing techniques (McNeill et al., 1971; Hinman and Johnson, 1974a). In vitro evidence suggests that different sorghum grain varieties vary substantially in rumen fermentability (Miller et al., 1972; Hibberd, 1979). The effect of sorghum grain variety on the site and extent of starch and protein digestion in vivo remains unknown. In vitro studies also suggest a variety dependent response to reconstitution (Hibberd, 1979). The magnitude of this response in vitro also is unknown.

The research reported in this dissertation utilized several widely divergent sorghum types (waxy, waxy bird resistant, normal and normal bird resistant) to evaluate the effects of: (1) nitrogen fertilization during growth on chemical composition and in vitro dry matter disappearance (IVDMD), (2) stage of maturity on developmental changes in chemical composition and IVDMD, (3) length of reconstitution on chemical composition and IVDMD, and (4) variety and reconstitution on the site and extent of starch and protein digestion in beef steers.

CHAPTER II

LITERATURE REVIEW

Sorghum grain has been traditionally discriminated against in high energy finishing rations for beef cattle. The feed industry generally discounts sorghum grain because it has a lower feeding value than corn grain (Morrison, 1959). The tremendous variation in chemical composition, digestibility and grain quality often observed for sorghum grain is probably a more serious problem. Some of this variation may be due to environmental factors that influence the growth and maturation of the sorghum kernel. Differences between varieties or endosperm types, however, also account for some variation in chemical composition and digestibility of sorghum grain (Hibberd, 1979).

The chemical composition and digestibility of sorghum grain varies considerably. For example, protein content of 44 varieties of sorghum ranged from 8.6 to 18.2%, lysine from 1.29 to 3.14% of crude protein (Virupaksha and Sastry, 1968), and starch content of nine varieties grown in three consecutive crop years ranged from 61.9 to 83.0% (Hibberd, 1979). McCollough (1972) noted wide differences in the mineral content of eight varieties of sorghum grain. Single stage <u>in vitro</u> digestibility ranged from 51.5 to 79.9% for 47 different sorghums (Miller et al., 1972). These differences in chemical composition and digestibility illustrate the variation which is responsible for irregular feeding results observed with sorghum grain. In addition, these ranges suggest

that the feeding value of some sorghum types (waxy sorghums) may be more similar to corn than others (Hibberd, 1979).

Variety or endosperm type and associated characteristics (tannin level, starch type, etc.) have been shown to affect the feeding value of sorghum grain. For example, sorghums with the waxy endosperm characteristic (95-100% amylopectin) are generally higher in digestibility and feeding value than nonwaxy sorghums (Nishimuta et al., 1969; Sherrod et al., 1969; McCollough and Brent, 1972). In contrast, high tannin bird resistant sorghums are utilized very poorly by cattle (McCollough and Brent, 1972; Maxson et al., 1973; White and Hembry, 1978). Some bird resistant types, such as those exhibiting a waxy endosperm, may not be as poorly utilized as others (Hibberd, 1979). Normal, regular and floury sorghum types are usually intermediate to the waxy and bird resistant in digestibility, some being very similar to waxy sorghum (Nishimuta et al., 1969; Miller et al., 1972; Hibberd, 1979).

The feeding value of sorghum grain usually is less than that of other cereal grains when both are dry rolled. Steers fed a barley diet gained 12% faster on 17% less feed than steers fed a dry rolled sorghum ration (Saba et al., 1964). Steers fed a corn diet gained 15% faster on 6% less feed than steers fed a sorghum diet (Maxson et al., 1973). Steam flaked sorghum, however, can produce cattle performance very similar to that achieved with steam flaked corn (Schake et al., 1976). Most feeders feel that intensive processing of sorghum grain is necessary to achieve animal performance comparable to that obtained with other cereal grains.

Adequate processing of sorghum grain can be achieved through several methods. A recent summary by Hale and Prouty (1980) illustrates

the potential for 15 to 17% improvement of feed use from steam flake, high moisture or dry heat processing of sorghum grain (Table 1). With adequate quality control, similar results can be achieved by any of these processing methods although the effect of each method on site of digestion or microbial efficiency may vary (McNeill et al., 1971; Hinman and Johnson, 1974a; Prigge et al., 1978).

Although sorghum grain usually responds very well to processing, some varieties or types of sorghum may respond better than others. Steam flaking doubled the in vitro dry matter disappearance (IVDMD) of a bird resistant while the IVDMD of a red sorghum remained unaffected (Saba et al., 1972). In terms of sheep performance, a bird resistant sorghum responded better to high moisture harvesting than a nonbird resistant type (Harpster et al., 1975). Reconstitution also appears to increase the IVDMD of bird resistant sorghums to a greater degree than other sorghum types (Hibberd, 1979). Because poorly digestible, i.e. bird resistant, sorghum grain varieties are usually improved by intensive processing more than others, the range in feeding value commonly observed with poorly processed sorghums may diminish when all varieties are well processed.

Kernel Structure and Composition

A basic knowledge of sorghum kernel structure and composition should facilitate greater understanding of varietal, environmental and grain processing effects. The sorghum kernel can be separated into five distinct components; the pericarp, aleurone, peripheral or corneous endosperm, floury endosperm and the germ (Figure 1). The pericarp is composed of several layers which surround the endosperm. The innermost

TABLE I. THE EFFECT OF GRAIN PROCESSING ON THE FEEDING VALUE OF SORGHUM GRAIN[ab]

	Dry Rolled or Ground	Steam Flaked	High Moisture	Popped, Exploded Micronized
Average Daily Gain, lb	2.56	2.76	2.76	2.76
Feed/day, lb (90% DM)	18.66	17.85 -4.3%	17.42 -6.6%	17.85 -4.3%
Feed/gain, lb (90% DM)	729	647	631	647
Improvement:				
For Total Ration		+11.2%	+13.4%	+11.2%
For Grain Only		+15.1%	+17.2%	+15.2%
Grain in Diet, %	74	74	78	74

[a]Adapted from Hale and Prouty, (1980).

[b]Average initial wt 540 lb; 140 days on feed.

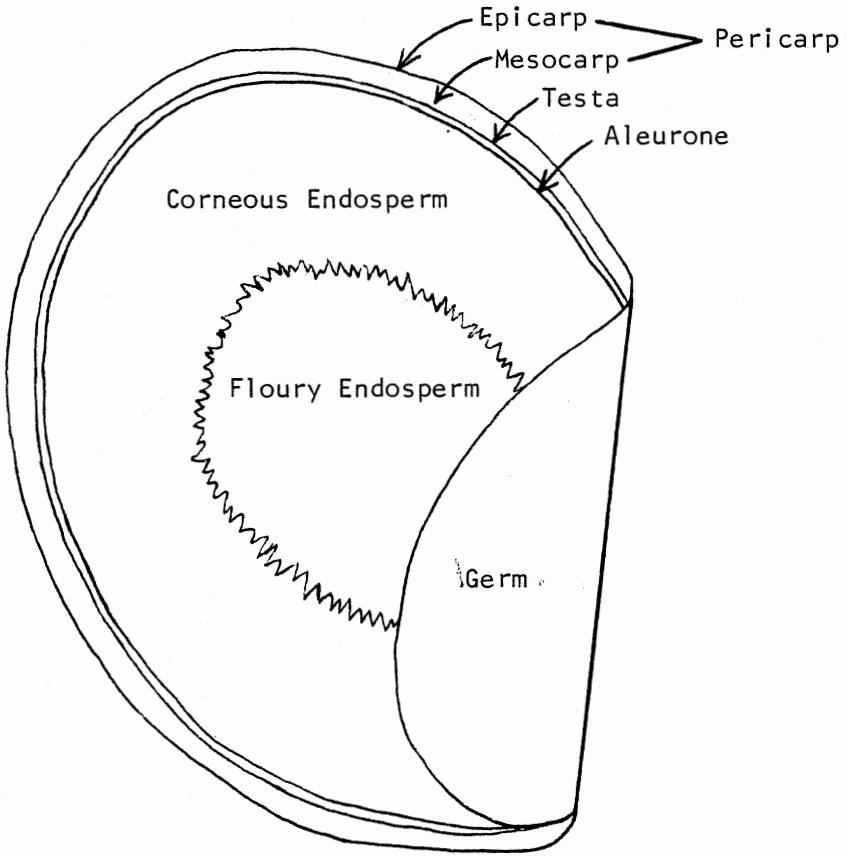


Figure 1. Schematic cross-section of sorghum kernel.

layer is the testa layer which, when present, increases the tannin content of the grain and results in bird repellancy (Wall and Ross, 1970). The aleurone layer is composed primarily of protein including many of the enzymes involved in germination. The peripheral endosperm surrounds the central, floury endosperm and is composed of starch granules and protein bodies tightly enmeshed in a dense protein matrix. The floury endosperm, in contrast, contains starch granules and protein bodies relatively unencumbered by matrix protein. The germ contains most of the genetic material and lipids as well as soluble albumin and globulin proteins.

Protein bodies of sorghum grain are primarily composed of kafirin (a prolamine), a storage protein with relatively low lysine content (Seckinger and Wolf, 1973). Kafirin is the least digestible protein in the sorghum kernel (Walker and Lichtenwalner, 1977). The protein bodies are storage sites for proteolytic and amylolytic enzymes that are released during germination (Adams and Novellie, 1975). Structural elements of the protein matrix are composed primarily of higher lysine glutelin protein (Seckinger and Wolf, 1973). Although more resistant to solubilization, glutelins are more digestible than kafirins (Walker and Lichtenwalner, 1977). Much of the improvement observed for processed grain sorghum may be due to release of starch through solubilization or disruption of glutelin in the protein matrix. The remainder of the protein in sorghum is soluble in water and salt (albumin and globulin) and is primarily associated with the germ and aleurone (Figure 1). Isolated albumins and globulins are fairly digestible, however, in aleurone cells they are associated with highly fibrous, cellulosic cell walls which may decrease their digestibility, especially for nonruminants

(Eggum, 1977).

Beyond differing in protein content, varieties differ in protein composition as well. Bird resistant sorghums usually contain less albumin and globulin and more glutelin than non-bird resistant types (Chibber et al., 1978; Guiragossian et al., 1978). Higher glutelin content may increase starch encapsulation through extension of the protein matrix. This mechanism may be responsible for the lower starch availability of bird resistant sorghums (Hibberd, 1979).

Starch granules generally increase in size from the peripheral to the floury endosperm (Figure 1). In sorghum, these granules consist of concentric ring structures very similar to potato starch (Badenhuizen, 1965). The α-amylase enzyme bores pinholes that enlarge within a ring to increase the surface area exposed for further attack (Harbers and Davis, 1974). Normal sorghum starch is composed of approximately 75% amylopectin and 25% amylose (French, 1973). In contrast, waxy starch contains little or no amylose and is more susceptible to enzymatic attack (Leach and Skoch, 1961). Studies with rumen bacteria, however, suggest that all sorghum starch is equally degradable when rendered accessible to microbial attack (Hibberd, 1979). Consequently, the increased dry matter digestibility of waxy sorghums must be attributed to factors other than starch type (Sandstedt et al., 1962). Perhaps increased solubility or digestibility of protein in waxy sorghum is responsible for increased digestibility (Sullins and Rooney, 1974; Hibberd, 1979).

In sorghum grain, tannins are associated with the presence of a testa layer (Reichert et al., 1980). The testa is a single cell layer that surrounds the endosperm between the pericarp and aleurone (Figure 1). High tannin levels give the sorghum kernel an astringent taste

which results in a degree of bird repellancy (Bullard et al., 1980). In addition, tannins decrease preharvest germination and increase yield per acre, both of which are favorable agronomic traits (Harris and Burns, 1970).

Tannins exert their primary nutritional effect through hydrogen bonding of protein molecules (McLeod, 1974). The nutritional status of the ruminant could be impaired by: (1) binding of feed proteins either before or during digestion (Glick and Joslyn, 1969; Schaffert et al., 1974), (2) inhibition of ruminal microbial activity (Tagari et al., 1965; Lyford et al., 1967; Singh and Arora, 1980), (3) binding of excess or freed tannins to digestive enzymes (Tamir and Alumot, 1969; Schaffert et al., 1974; Chibber et al., 1980), and (4) toxic action of absorbed tannin on blood or cellular constituents (Potter and Fuller, 1968). The first three effects could decrease protein digestibility and subsequently limit starch utilization. Although any of these effects could decrease the nutritional value of bird resistant sorghum, microbial fermentation during ensiling or ruminal digestion may partially degrade or inactivate tannins (Cummins, 1971). Sorghum processing by steam flaking or reconstitution appears to decrease tannin content (Saba et al., 1972; Reichert et al., 1980). These mechanisms, however, do not obliterate all of the tannin from bird resistant sorghum grain. Consequently, the potential effects of tannin on digestion and absorption in the ruminant are not fully eliminated by processing.

Environmental Effects on Sorghum Composition and Digestibility

During growth and maturation of the sorghum plant numerous environ-

mental factors can alter the chemical composition and potential feeding value of the grain. For example, hot, dry growing conditions prevent full growth of kernels and since starch is deposited last, smaller kernels contain less starch and more protein (Heller and Sieglinger, 1944). Light intensity, soil or air temperature, relative humidity or soil type could also affect the growth and development of the sorghum kernel. Another variable but controllable factor is soil fertility, especially the amount of nitrogen fertilizer applied either before or during the growing season.

Faster growing, earlier maturing hybrids, irrigation and the pressure for maximum yield have increased response to and use of nitrogen fertilizer on grain sorghum. Nitrogen application can dramatically increase grain yield (Burleson et al., 1956; Miller et al., 1962). At nitrogen levels which maximize yield, kernel protein content can vary. When nitrogen is adequate during vegetative growth but deficient during head formation, yield may remain unaffected and endosperm protein may be decreased. Alternatively, extra nitrogen during vegetative growth and head formation may increase protein deposition in the endosperm (Wall and Ross, 1970). Nitrogen fertilization can increase protein content of a single variety from 8 to 12% of DM (Wall and Ross, 1970). Nitrogen fertilization usually increases crude protein content of sorghum grain dramatically (Burleson et al., 1956; Miller et al., 1962; Eng et al., 1965).

Nitrogen fertilization also may affect other protein characteristics. Albumin and globulin content (mg/kernel) remain fairly constant, so increases in crude protein reflect increased prolamine and glutelin deposition (Virupaksha and Sastry, 1968; Eggum, 1977). The low lysine

content of prolamines may be responsible for the reduction in protein quality of fertilized sorghum grain (Waggle et al., 1967). In addition, increased glutelin deposition may extend the protein matrix of the endosperm which may encapsulate additional starch and decrease starch utilization of unprocessed grain.

The effect of nitrogen fertilization on digestibility or growth rate of cattle remains unknown. Eng et al. (1965) reported that protein digestibility and nitrogen retention increased with fertilization of sorghum grain. In their trial, intake was equalized on the basis of protein content, so increased digestibility of energy from fertilized sorghum may have been a result of the lower level of feed intake used with the higher protein grain.

Effect of Stage of Maturity

Increased cost of energy for processing cereal grains has prompted cattle feeders to consider processing systems more energy efficient than steam flaking or micronizing. High moisture methods (reconstitution or high moisture harvest) require less energy than steam flaking and can produce similar results (Hale and Prouty, 1980; Mies and Summers, 1980). High moisture harvest involves threshing the grain at 28 to 30% moisture and packing the material into a bunker silo. Unlike corn, sorghum grain should be ensiled whole to achieve maximum benefits. Due to problems with oxygen exclusion, chemical preservatives (propionic, acetic or other organic acids) are often applied to help maintain feed quality.

The mechanism by which high moisture harvest increases feeding value is not known, although a combination of grain immaturity and postharvest fermentation seems involved. Chemical composition changes throughout

maturation, even after dry matter deposition is complete (32 to 35% moisture). Nitrogen deposition (mg/berry) is often complete within 25 days postpollination (Kersting et al., 1961). This reflects cell multiplication (hyperplasia) early in development followed by starch deposition and cell enlargement (hypertrophy) at later stages. Starch content may not peak until 32 days after pollination (Kersting et al., 1961). Soluble albumin and globulin proteins predominate early in the maturation process while glutelin and especially kafirin are deposited later (Wall and Ross, 1970; Misra and Mertz, 1975).

Starch deposition (g/berry) increases rapidly through day 38 post-pollination (Kersting et al., 1961). Percent starch increases at a similar rate suggesting that carbohydrate deposition is more rapid than protein deposition from day 5 through 38 (Kersting et al., 1961). In corn, 88% of the total starch deposition occurs within 25 days post-pollination (Gentinetta et al., 1979). Changes in starch composition also occur. Amylose content of corn starch increases throughout maturity as does granule size suggesting that larger starch granules are older and contain more amylose than smaller granules (Boyer et al., 1976).

In bird resistant sorghums, tannin content peaked between 20 and 30 days after 50% anthesis and declined by as much as 80% at maturity (Davis and Hoseney, 1979; Price et al., 1979a; Glennie, 1981). Tannin subunits probably polymerize throughout maturation so that the number of biologically active molecules decreases with time (McLeod, 1974). Mineral content (ppm/berry) of maturing wheat and rye continues to increase from four weeks before maturity through harvest (Lorenz and Reuter, 1976).

Changes in chemical composition that occur through maturity may result in changes in digestibility as well. In vitro digestibility of high moisture (22%) corn was 4.1 percentage units higher than dry (16%) corn (Danley and Vetter, 1974b). Crude protein digestibility however, appears to increase as the grain matures (Harpster et al., 1975; Prigge et al., 1976). Although protein digestibility of high moisture harvested grain may be depressed, the increase in feed efficiency for high moisture grain probably results from greater starch availability compared to dry grain.

Reconstitution of Sorghum Grain

The addition of water to dry sorghum grain and storage under anaerobic conditions for 21 days (reconstitution) is an energy efficient and nutritionally effective grain processing technique (Totusek et al., 1967; Newsom et al., 1968; White et al., 1969). When compared to dry rolled sorghum, reconstituted grain matches steam flaking in growth rate and may result in even better feed conversion (Hale and Prouty, 1980). Variable responses in growth rate (-3.9 to +12%) and feed efficiency (-4.3 to +28.1%) across 15 trials suggests that responses to reconstitution are not consistent (Hinders, 1976). Much of this variation may be due to experimental conditions, though some may relate to variety or source of sorghum grain. The response to steam flaking and reconstitution appears to be variety dependent (Saba et al., 1972; Hibberd, 1979).

The improvement in feed efficiency due to reconstitution is probably due to increased protein and starch digestibility (Buchanan-Smith et al., 1968; McNeill et al., 1971; Potter et al., 1971). Increased starch digestibility may result from changes in the protein matrix

since the amyloglucosidase digestibility of starch from reconstituted and dry ground sorghum is similar (McNeill et al., 1975). Reconstitution could alter the integrity of the protein matrix by: (1) disrupting or solubilizing due to germination, (2) imbibing water causing swelling and fracture of the kernel, or (3) microbial action during fermentation. Each of these mechanisms could increase the accessibility of sorghum starch to digestive action (Sullins et al., 1971; Walker and Lichtenwalner, 1977; Lichtenwalner et al., 1979). Levels of soluble protein and available starch are high without processing for some sorghum grain varieties such as waxy types. The magnitude of the response to reconstitution may be greater when these levels are lower (Hibberd, 1979).

Another factor that may preferentially enhance the reconstitution response of bird resistant sorghums is the deactivation of tannin which occurs when water is imbibed (Reichert et al., 1980). Tannin content can decrease by 30 to 50% when water is added to sorghum grain (Chavan et al., 1979; Price et al., 1979b). Decreases in tannin content were similar when sorghum was reconstituted to 25% moisture or when it germinated (Reichert et al., 1980). Fermentation may reduce the tannin content further during reconstitution (Cummins, 1971).

Changes in the chemical components of the sorghum kernel occur very rapidly during reconstitution. During germination of corn, soluble protein increases 4-fold and soluble carbohydrates increase 3-fold within 72 hours (Ingle et al., 1964). Germination of a bird resistant sorghum decreased tannin content by 65% within four days (Reichert et al., 1980). These studies suggest that many of the changes related to reconstitution may occur very early in the process.

A storage period of at least 20 days for full benefit of reconsti-

tution may be required (Pantin et al., 1969; Wagner and Schneider, 1970; Neuhaus and Totusek, 1971; Wagner et al., 1971). Much of the benefit of reconstitution, however, can be realized within 5 to 10 days (Pantin et al., 1969; Wagner et al., 1971). Shorter term reconstitution would increase turnover rate of processed sorghum so that larger operations could reduce the grain inventory and storage structures needed to reconstitute grain.

Factors Affecting the Site and Extent of Cereal Grain Starch and Protein Digestion

One of the major goals of nutritionists and feed manufacturers in the last 20 to 30 years has been to increase the digestibility of feedstuffs to maximize efficiency of conversion of feed to lean tissue. Development of grain processing techniques, feeding regimes, supplementation schemes and certain feed additives have increased digestion and utilization of feedstuffs and enhanced animal performance. Some of these techniques not only increase total digestibility but also alter the site (ruminal vs. intestinal) of digestion and absorption of various nutrients. The potential benefit of changing the site of digestion can be illustrated through theoretical calculations which show that a nonruminant lamb in which feed would not be digested in the rumen but only in the intestines could draw 10 to 60% more productive energy and almost twice as much net protein from a high concentrate feed than a ruminant lamb (Black, 1971).

With high concentrate feeds, the efficiency of starch utilization may be increased by shifting starch digestion to the small intestine.

The ruminant has considerable ability to digest starch in and absorb glucose from the small intestine (Ørskov, 1977). Absorption of digested starch as glucose should increase efficiency since heat and methane losses with ruminal fermentation would be avoided (Black, 1971; Sutton, 1971). An additional benefit of intestinal digestion of starch is the contribution of absorbed glucose to the glucose requirement of the animal. This mechanism should spare ruminally absorbed propionate and glucogenic amino acids for other productive pruposes. Armstrong (1965) estimated the glucose requirement of sheep at 4.4 g per kilogram of metabolic weight ($kg^{.75}$). For a 300 kg steer, this would represent about 320 g of glucose or 285 g of starch. On an 88% corn ration, only about six percent of ingested starch would have to reach the duodenum to satisfy this requirement. A glucose deficiency may not be a problem except with gelatinized starch where ruminal digestion is extensive (Ørskov et al., 1969; Cole et al., 1976b).

Before developing rations to maximize ruminal bypass of starch, one must recognize that there may be a limit to the amount of starch that the small intestine can digest and/or absorb (Karr et al., 1966). Fermentation in the lower gut (large intestine, cecum and colon) can compensate to an extent, although the inefficiencies of fermentation are again realized and most of the microbial mass synthesized in the lower gut is merely excreted (Ørskov et al., 1970; DeGregorio et al., 1982). Consequently, the most desirable situation would be to maximize ruminal bypass of starch and yet insure complete digestion and absorption in the small intestine (Waldo, 1973).

With regard to nitrogen utilization, ruminal bypass of starch decreases the quantity of energy available in the rumen and decreases the

amount of microbial protein produced (Armstrong and Smithard, 1979). When dietary protein is poorly digestible or of low quality, a protein deficiency or an amino acid imbalance could result. When feed intake is increased, however, starch bypass, dietary protein bypass and microbial protein synthesis are all increased (Zinn and Owens, 1981).

Ruminal Fermentation of Starch and Protein

Many factors can affect the extent of ruminal fermentation of dietary starch and protein. Perhaps the most obvious effect on ruminal starch fermentation is that of grain processing (Table II). As little as 42% of ground sorghum starch may disappear in the rumen whereas fermentation of steam flaked sorghum starch may reach 83% (McNeill et al., 1971). Differences between ruminal fermentation of dry ground grain and steam flaked grain are less apparent with corn than with sorghum. This may account for the greater performance response of sorghum than corn grain to intensive processing. Differences in ruminal digestion rate between dry processed and steam flaked grain are more difficult to assess. Dry rolled or cracked grain may be retained longer in the rumen than steam flaked grain (Johnson et al., 1968). Reconstitution of sorghum grain increases ruminal starch digestion slightly, but the major response in feed efficiency may be due to increased starch availability in the intestines (McNeill et al., 1971). Differences in ruminal starch digestion of steam flaked and reconstituted sorghum grain are probably attributable to gelatinization of starch in heat treated grain (Osman et al., 1970).

Both steam flaking and reconstitution of sorghum grain appear to increase protein degradation in the rumen (Table III). Dry heat process-

TABLE II. RUMINAL DIGESTION OF PROCESSED CORN OR SORGHUM STARCH (%)

Grain	Species	Processing Method							Adapted from
		Whole	Dry Ground	Dry Rolled	Recon-stituted	Steam Flaked	Micro-nized	High Moisture Harvested	
Corn	Sheep		78.0			95.7			Beever et al., 1970
Corn	Sheep					94.1			Nicholson and Sutton, 1969
Corn	Sheep					89.6			MacRae and Armstrong, 1969
Corn	Sheep		87.9	85.8		94.6			Ørskov et al., 1969
Corn	Cattle			71.7		91.6			Cole et al., 1976b
Corn	Cattle	61.1				91.1			McCullough and Matsushima, 1973
Corn	Cattle			77.8		83.0		89.3	Galyean et al., 1976
Sorghum	Sheep					90-95			Holmes et al., 1970
Sorghum	Cattle		42.0		66.7	83.4	43.0		McNeill et al., 1971
Sorghum	Cattle		86.3	76.5		81.3	84.2		Hinman and Johnson, 1974a
Sorghum	Cattle			60			64		Hinman and Johnson, 1974b

TABLE III. RUMINAL DEGRADATION OF PROCESSED GRAIN PROTEIN (%)

		Processing Method					
Grain	Species	Dry Ground	Dry Rolled	Recon-stituted	Steam Flaked	Micro-nized	Adapted from
Barley	Sheep		96		87	75	Papasolomontos et al., 1976
Corn	Sheep		70		51	60	Papasolomontos et al., 1976
Corn	Sheep	14.8					Ørskov et al., 1971
Corn	Cattle		13.1				Neudoerffer et al., 1971
Corn	Cattle	57.6	57.6		65.0		Cole et al., 1976b
Sorghum	Cattle	51.3		79.5	62.2	36.1	Potter et al., 1971

ing (micronization) may decrease ruminal protein degradation due to denaturation and agglutination of protein. Decreased ruminal degradation of dietary protein will increase the quantity of grain protein reaching the duodenum. Total nonammonia nitrogen flow should increase if dietary NPN or nitrogen recycling is adequate (Potter et al., 1971; Cole et al., 1976c). Increased dietary protein presented to the duodenum is only of value when that protein is highly digestible which may not be the case for extensively heat treated protein as found with micronized sorghum grain (Potter et al., 1971).

Increasing feed intake can also shift digestion away from the rumen, apparently by increasing rate of passage (Galyean et al., 1979). Increasing intake of a low roughage (prairie hay) rolled corn diet from 1.5 to 2.0% of body weight decreased ruminal starch digestion from 88 to 59% (Zinn and Owens, 1980b). A second study with cottonseed hulls as the roughage source, however, showed increased ruminal starch fermentation, from 79.6% at 1.2% of body weight up to 91.0% at 2.1% of body weight (Zinn and Owens, 1982b). A small decrease in ruminal starch digestion was observed with sheep when steam flaked corn was fed (Nicholson and Sutton, 1969). Ruminal protein degradation is also decreased with higher levels of feed intake (Zinn and Owens, 1981).

Ruminal digestion of starch decreases as roughage level in the diet is increased (Karr et al., 1966; Cole et al., 1976a; Zinn and Owens, 1980b). Intestinal digestion may compensate to some extent although total digestibility of starch can be depressed (Cole et al., 1976a). Higher roughage levels increase liquid dilution rate and may result in greater washout of small grain particles (Van Soest, 1982). Increased small grain particle washout with higher roughage could also decrease

ruminal degradation of grain protein (Zinn and Owens, 1980b).

The source or variety of grain may affect the extent of rumen digestion. Starch digestion of barley occurs very rapidly in the rumen, corn and wheat are fermented at intermediate rates and sorghum is fermented more slowly (MacRae and Armstrong, 1969; Ørskov et al., 1971; Thivend and Vermorel, 1971). In vitro studies suggest that different varieties or endosperm types of sorghum have different rates of ruminal digestion (Miller et al., 1972; Hibberd, 1979). Ruminal carbohydrate digestion was greatest for a floury sorghum (80.1%) followed by waxy (75.0%), normal (68.1%) and corneous (48.4%) endosperm types (Samford et al., 1971).

Adequate levels of available nitrogen are needed in the rumen to maximize fermentation and production of microbial protein (Church, 1976). Cereal grain proteins generally are poorly soluble in water, especially when unprocessed, and may precipitate ruminal nitrogen deficiencies (Wohlt et al., 1973). Ruminal starch digestion and DAP production were less on a corn diet than a barley diet, possibly due to a deficiency of nitrogen in the rumen (Ørskov et al., 1971). Satter and Slyter (1974) indicated that rumen ammonia levels of 5 mg/dl are adequate for maximal microbial growth although Mehrez and Ørskov (1976) suggest that 23 mg/dl were required for maximal rumen digestion. Ammonia concentrations between 5 and 8 mg/dl have been observed for ewes fed flaked corn (Annison et al., 1954). Isolated corn protein fed as the sole source of nitrogen resulted in ruminal ammonia levels around 15 mg/dl (Hembry et al., 1975). These ammonia levels may be marginally adequate. Addition of 1% urea to sorghum rations increased apparent digestibility of dry matter, energy and protein suggesting that the rumen may have

been deficient in ammonia (Greathouse et al., 1974).

Elevated dietary tannin levels commonly observed with bird resistant sorghums also may decrease ruminal digestion (Saba et al., 1972; Hibberd, 1979). Tannin extracts decreased cellulolysis, proteolysis, deamination and protein biosynthesis in an artificial rumen (Tagari et al., 1965). Tannin treatment of a high quality dietary protein can increase nitrogen retention, growth rate and feed efficiency, apparently through bypass of high quality protein to the duodenum (Driedger and Hatfield, 1972). Although microbial action may partially inactivate tannins, undegraded tannins could still affect ruminal and intestinal digestion.

Nitrogen Flow and Microbial Efficiency

Total flow of nonammonia nitrogen to the duodenum may be increased when roughage levels or feed intake are increased (Table IV). Part of this increased nitrogen flow is due to increased microbial nitrogen production although bypass of feed nitrogen also increases (Zinn and Owens, 1981). Greater intake of dry matter or roughage increases rate of passage, thereby decreasing exposure of feed particles to rumen action and increasing dietary protein escape (Table IV). In addition, increased rate of passage increases microbial growth rate resulting in greater efficiency of microbial protein production (Owens and Isaacson, 1977; Table IV).

The effect of grain processing on microbial growth and efficiency is difficult to assess at present. Estimates of dilution rate and microbial growth conflict (Table IV). Intensive processing, however, enhances ruminal fermentation and without adequate roughage, may adversely affect microbial efficiency (Cole, 1975; Table IV). A greater

TABLE IV. MICROBIAL PROTEIN PRODUCTION AND EFFICIENCY OF VARIOUS GRAIN DIETS

Diet	Dry Matter Intake		Abomasal Passage (g/day)		Dilution Rate (%/h)	Microbial Efficiency[a]	Adapted From
	kg	% BW	Nonammonia N	Microbial N			
Whole shelled							
Corn	4.46	1.14	66.2	34.0	2.8	7.0[b]	Cole
+7% CSH	5.23	1.34	74.0	40.3	4.4	8.6[b]	et al.,
+14% CSH	5.69	1.46	124.9	47.1	5.0	9.5[b]	1976c
+21% CSH	5.93	1.52	119.9	57.4	4.3	10.9[b]	
Corn (% CSH)							
Dry rolled (0)	4.35	0.94	59.8	25.2	2.8	5.9[b]	Cole,
Dry rolled (21)	5.35	1.16	98.9	48.8	4.0	10.3[b]	1975
Steam flaked (0)	4.36	0.95	48.8	22.9	2.3	4.5[b]	
Steam Flaked (21)	5.32	1.16	86.1	42.1	3.6	7.3[b]	
Corn							
Dry rolled	4.40	1.02	77.1	29.2	3.2	8.9[c]	Prigge
High moisture ensiled	4.44	1.03	82.5	35.2	4.0	10.0[c]	et al., 1978
Steam flaked	4.49	1.05	87.1	35.4	3.3	9.4[c]	
Corn							
Dry rolled	4.5	1.46	118	41		15.2[c]	Zinn and
+2.5 $CaCO_3$	4.5	1.46	119	47		13.0[c]	Owens,
+1.0 $NaHCO_3$	4.6	1.49	134	46		13.8[c]	1980a
Dry rolled corn (% in diet)							
65%	3.0	1.30	55.0	27.8		10.7[c]	Zinn and
65%	4.6	1.99	102.3	41.8		12.4[c]	Owens,
43%	4.0	1.73	93.9	43.5		13.1[c]	1980b
Sorghum							
Dry rolled			192	90.2		24	Theurer,
Steam flaked			187	99.5		17	1979

[a]Ruminally fermented dry (organic) matter adjusted for microbial dry (organic) matter based on microbial composition of 20% ash, 50% crude protein.

[b]MOEFF = g MOCP/100 g ruminally fermented dry matter.

[c]MOEFF = g MOCP/100 g ruminally fermented organic matter.

proportion of poorly processed grain, in contrast, may leave the rumen undigested resulting in decreased fermentation, increased passage rate, increased microbial protein production and increased microbial efficiency (Table IV). Efficiency of energy utilization by the animal may be decreased in this situation due to impaired starch digestion in the intestines (Hinman and Johnson, 1974a).

Intestinal Digestion of Starch and Protein

In order to maximize efficiency of feed use, unfermented feed and microbial mass leaving the rumen must be digested and absorbed in the intestines. Efficiency is greatest if postruminal digestion occurs in the small intestine. As much as 1405 g of starch can be digested and absorbed in the small plus large intestine of a 250 kg steer. This suggests that postruminal starch digestion can be substantial (Hinman and Johnson, 1974b). This amount of starch equals about 5.2 mcal of metabolizable energy or 30% of the metabolizable energy requirement of this steer (NRC, 1976).

Intestinal digestion of sorghum starch appears to be fairly complete once that starch is made accessible to amylolytic enzymes (Table V). Disruption of the protein matrix through heat processing, solubilization (reconstitution) or fine grinding adequately exposes the starch for enzymatic attack. Dry rolling, however, appears to be least effective (Hinman and Johnson, 1974b).

When ruminal fermentation of starch is incomplete, digestion in the small and large intestine becomes more critical (Table VI). Increased grain intake increases the quantity of starch presented to and digested in the small intestine (Karr et al., 1966; Zinn and Owens,

TABLE V. SMALL PLUS LARGE INTESTINAL DIGESTION OF SORGHUM STARCH

Ration or Process	Starch Intake		Intestinal Digestion			Small + Large Intestinal Digestibility	Total Tract Digestibility	Adapted From
	g	% BW	g	g/BW$^{.75}$	% of intake			
Dry ground	2070	.56	1133	13.4	54.7	94.4	96.8	McNeill et al., 1971
Reconstituted	2280	.62	748	8.9	32.8	98.4	99.5	
Steam flaked	2290	.62	374	4.4	16.3	98.4	99.7	
Micronized	2140	.58	1159	13.7	54.2	95.0	97.1	
Dry rolled	3722	1.65	592	10.2	15.9	67.7	92.4	Hinman and Johnson, 1974a
Ground	2687	1.19	336	5.8	12.5	91.3	98.8	
Steam flaked	3737	1.66	661	11.4	17.7	94.6	99.0	
Micronized	3382	1.50	520	9.0	15.4	97.4	99.6	
Dry rolled	3494	1.40	744	11.8	21.3	50.9	81.4	Hinman and Johnson, 1974b
Micronized								
Low	3778	1.51	1405	22.3	37.2	95.4	98.0	
Medium	3914	1.56	1338	21.3	34.2	95.5	98.3	
High	3746	1.50	1120	17.8	29.9	92.9	97.8	

TABLE VI. SMALL VS. LARGE INTESTINAL DIGESTION OF STARCH

Ration or Process	Starch Intake		Digestion in Small Intestine			Digestion in Large Intestine			Total Tract Digestibility	Adapted From
	g	% BW	g	g/BW$^{.75}$	% of Intake	g	g/BW$^{.75}$	% of Intake		
Ground corn										
20% corn	1002	0.28	331	4.0	33	14	0.2	1	99	Karr
40% corn	1948	0.54	463	5.6	24	62	0.8	3	99	et al.,
60% corn	2438	0.68	609	7.4	25	129	1.6	5	98	1966
80% corn	2684	0.74	624	7.6	23	296	3.6	11	98	
Dry rolled corn										
+2.5% $CaCO_3$	2387	0.78	631	8.6	26	423	5.8	18	95	Zinn and
+2.5% $CaCO_3$ +	2387	0.78	513	7.0	21	123	1.7	5	97	Owens,
1% $NaHCO_3$	2387	0.78	551	7.5	23	182	2.5	8	96	1980a
Dry rolled corn										
65% corn	1535	0.67	298	5.0	19	30	0.5	2	99	Zinn and
65% corn	2356	1.02	826	14.0	35	67	1.1	3	97	Owens,
43% corn	1560	0.68	361	6.1	23	54	0.9	3	98	1980b

1980b). The capacity of the small intestine for starch digestion and absorption may be exceeded, in which case large quantities of starch may be fermented in the large intestine. As much as 18% of dietary starch can disappear in the large intestine (Zinn and Owens, 1980a). This illustrates the digestive capacity of this organ. If the quantity of starch entering the large intestine is not too great, starch digestion in the total tract may be essentially complete (Table VI). Decreased propionate: acetate and loss of microbial protein during large intestinal fermentation, however, dictate that starch spillover into this organ should be avoided (Ørskov et al., 1970).

Several characteristics of sorghum grain may limit intestinal digestion of starch and protein. Starch digestion of processed sorghum grain may be limited by the integrity of the protein matrix of grain particles reaching the duodenum. Grain processing techniques that result in solubilization (reconstitution) or disruption (steam flaking or micronization) of the protein matrix increase digestibility of sorghum starch in the small plus large intestine (Table V). Gelatinization of starch by heat processing may further enhance intestinal digestibility (Osman et al., 1970). Intestinal digestion of processed sorghum protein appears to vary only slightly although differences in small intestinal digestion may be masked by compensatory fermentation in the large intestine (Potter et al., 1971).

Certain varietal characteristics of sorghum also may limit small intestinal starch digestion. Normal sorghum starch is composed of 75% amylopectin and 25% amylose (French, 1973) whereas waxy sorghum starch is almost entirely amylopectin, a highly branched polymer that is very susceptible to enzymatic attack (Leach and Skoch, 1961).

In addition, waxy sorghums often contain more soluble protein (albumin and globulin) and less insoluble protein (glutelin) than other sorghum types, especially bird resistant varieties (Hibberd, 1979). Consequently the protein matrix of waxy sorghums may be less dense and less of a barrier to enzymatic attack in the small intestine.

Bird resistant sorghums may contain high levels of condensed tannins (Maxson et al., 1973). If passed to the duodenum intact, tannins decrease intestinal starch digestion by: (a) reducing the digestibility or solubility of matrix protein causing decreased starch accessibility, or (b) inactivation of proteolytic or amylolytic enzymes secreted by the pancreas or intestinal mucosa. Because dietary tannins could hinder feed utilization at many levels, efforts to destroy or inactivate tannins before feeding should be pursued.

The Use of Cannulated Animals to Measure Site and Extent of Digestion

Early site and extent of digestion work utilized slaughter techniques (Weller and Gray, 1954). This technique is limited by slaughter trauma as well as the impossibility of multiple observations on the same animal. Samples obtained from ruminal cannulae may offer useful information though one must assume that the cannula does not alter ruminal function and that rumen contents collected are representative of material presented to the duodenum. Because of omasal filtration, representative sampling of effluent is difficult or impossible. Recently, intestinal cannulation techniques have been developed which minimize trauma and damage to the intestine and allow sampling with minimal stress to the animal (McGilliard, 1982). The ability of intes-

tinally cannulated animals to digest feed, grow and produce does not appear to be hambered (Hayes et al., 1964; MacRae and Wilson, 1977). Placement of cannulae, proximal or distal to the bile duct, for example, will influence interpretation of the results but offers experimental flexibility. Differences in cannula design (T-type vs. reentrant) and sampling technique (spot vs. total collection) are other variations that can be standardized. Application of these techniques should rapidly enhance our knowledge of ruminal and intestinal function.

CHAPTER III

THE EFFECT OF NITROGEN FERTILIZATION ON CHEMICAL COMPOSITION AND IVDMD OF SEVERAL VARIETIES OF SORGHUM GRAIN

A waxy (Dwarf Redlan), waxy bird resistant (1133), normal (Redlan), and two normal bird resistant (ROKY 78 year 1 only and Darset) sorghums were grown and harvested in adjacent plots under dryland conditions for two crop years to determine the effect of nitrogen fertilization on composition and *in vitro* dry matter digestibility. Additional nitrogen (56 kg/ha) was added to a portion of each varietal plot midway through the growing season. Nitrogen (N) fertilization had little effect on starch (%) or tannin content although starch deposition (g/berry) was correlated with berry size ($r = .99$ in year 1, $r = .93$ in year 2). When additional N increased berry size, protein content (%) changed very little. When berry size was unaffected by N addition, protein content (%) increased. Protein deposition (g CP/berry) was increased by N addition in year 1 but decreased for the Dwarf Redlan and Darset in year 2, mainly due to decreases in berry size. Nitrogen fertilization had relatively little effect on protein composition (% of crude protein). When expressed as mg protein/berry, however, increased protein content (%) was reflected by increased kafirin and glutelin deposition. When protein content (%) remained constant, increased berry size was associated with similar increases in all protein fractions (mg/berry).

Additional N increased the *in vitro* dry matter disappearance (IVDMD) of the Darset in year 1 and all sorghum varieties in year 2. These studies suggest that additional nitrogen fertilizer applied during the growing season can alter the chemical composition of sorghum grain and may increase digestibility.

Introduction

Various environmental factors that affect the growth and maturation of the sorghum plant may ultimately influence the chemical composition and feeding value of the grain. Hot, dry growing conditions result in smaller kernels that contain more protein and less starch than normal (Heller and Sieglinger, 1944). Agronomic practices, such as nitrogen fertilization, also may alter chemical composition of sorghum grain (Wall and Ross, 1970).

When soil nitrogen levels are deficient, fertilization can dramatically enhance sorghum grain yield (Burleson et al., 1956; Miller et al., 1962). Increasing levels of nitrogen application can increase the protein content of the grain, even after yield is maximized (Burleson et al., 1956; Miller et al., 1962; Eng et al., 1965). Increasing the protein content of cereal grains usually results in a decrease in lysine as a percent of total protein (MacGregor et al., 1961; Waggle et al., 1967). Decreased lysine is indicative of kafirin (low lysine protein) deposition (Munck, 1964; Virupaksha and Sastry, 1968). Increased protein deposition also may increase glutelin content which may extend the protein matrix and increase the degree of starch encapsulation (Eggum, 1977).

When protein content of barley was raised by nitrogen fertilization,

rat growth and feed efficiency increased (McBeath et al., 1960). The effect of nitrogen fertilization on digestibility or growth rate in ruminants is less clear. Although Eng et al. (1965) reported increased protein digestibility and nitrogen retention with fertilized sorghums, intake of protein was equalized by changing dry matter intake which may have inflated the digestibility of the high protein sorghums. Because prolamines (kafirin or zein) are poorly digested in the rumen, increased kafirin content due to nitrogen fertilization may decrease overall protein digestibility (Walker and Lichtenwalner, 1977).

Consequently, the effect of nitrogen fertilization of sorghum grain on ruminant nutrition is not well understood. The effect of nitrogen fertilization on starch content and availability and tannin concentration is not known. The objective of this study was to evaluate the effect of extra nitrogen fertilization on protein, starch and tannin deposition, protein composition and *in vitro* digestibility of several varieties of sorghum grain.

Materials and Methods

Five widely divergent varieties of sorghum grain were grown and harvested under similar dryland conditions for two crop years at the Agronomy Research Station, Perkins, OK (Table VII). Rainfall patterns, planting and harvest dates are displayed in Figure 2. Sorghum types represented were a waxy (Dwarf Redlan), a waxy bird resistant (1133), a normal (Redlan) and two normal bird resistants (ROKY 78 and Darset). Preemergence fertilizer (18-46-0) was applied at a rate of 112 kg/ha in year 2 only. Midway through the growing season, extra N was added to a portion of each varietal plot at a rate of 56 kg per hectare. After

TABLE VII. DESCRIPTIVE CHARACTERISTICS OF SORGHUM GRAIN VARIETIES

Variety	Seed Coat Color	Endosperm		Classification
		Color	Starch	
Dwarf Redlan	Red	White	Waxy	Waxy
1133	Brown	Yellow	Waxy	Waxy - BR[a]
Redlan	Red	White	Normal	Normal
ROKY 78[b]	Brown	Yellow	Normal	Normal - BR[a]
Darset	Brown	White	Normal	Normal - BR[a]

[a]BR = Bird resistant.

[b]Year 1 only.

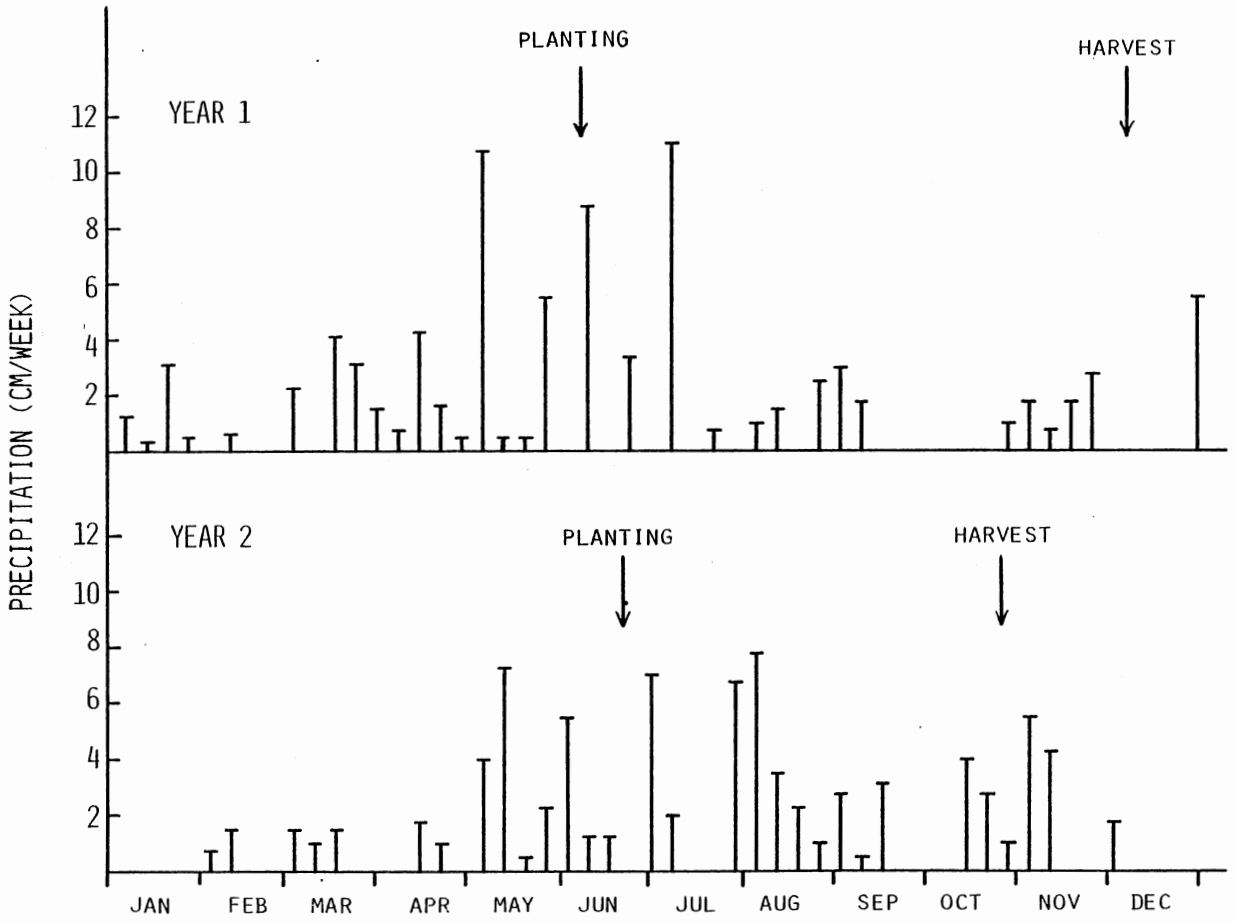


Figure 2. Rainfall patterns and planting and harvest dates.

harvest, each grain sample was finely ground through a .4 mm screen in a Udy mill for chemical analysis or through a 20-mesh (1 mm) screen in a Wiley mill for evaluation of digestibility. Berry size was estimated in triplicate by weighing three different groups of 100 berries each. Crude protein content was measured by Kjeldahl (N X 6.25) and starch as α-linked glucose polymers (MacRae and Armstrong, 1968). Tannin content was determined using a vanillin-HCl procedure (Burns, 1971) as modified by Price et al. (1978). Protein types (albumin and globulin, kafirin and glutelin) were separated by differential solubility (Landry and Moureaux, 1970). The effect of N fertilization on relative digestibility was evaluated with a 24-h single stage in vitro dry matter disappearance (IVDMD) procedure (Hibberd, 1979). Urea (20 mg/tube) was added to insure adequate fermentable N concentration.

Data obtained from these studies can be described by the model:

$$Y_{ijk} = \mu + V_i + F_j + R_k + VF_{ij} + E_{ijk}$$

where Y_{ijk} is 24-h IVDMD, V is variety, F is fertilization level, R is run and VF is the variety by fertilization level interaction. The components μ, V_i, F_j and R_k were treated as fixed effects of all records of variety i, fertilization level j and run k. Random error effect, E_{ijk}, was specific to each observation. Interactions involving run effects were assumed to be zero. Models for chemical analyses were identical except for deletion of the run term.

Estimated differences between variety X fertilization level means were obtained by method of least squares. Fertilization level effects within each variety were tested only when the variety X fertilization level interaction was significant. Significant effects were detected by t-test (Federer, 1967).

Results and Discussion

Additional nitrogen fertilizer increased ($P < .05$) the protein content (%) of the Dwarf Redlan (+.93 unit) and 1133 (+.92 unit) in year 1 and the Dwarf Redlan (+.57 unit), Redlan (+1.43 unit) and Darset (+.61 unit) in year 2 (Table VIII). Percent protein remained unchanged for the Redlan, ROKY 78 and Darset in year 1 but decreased ($P < .05$) by .6 unit for the 1133 in year 2. Nitrogen fertilization can raise the protein content of sorghum grain by as much as 3.9 units, the size of the response dependent on existing soil levels (Burleson et al., 1956; Miller et al., 1962; Waggle et al., 1967). Nitrogen fertilization can increase protein content by as much as 1.3 units, even after yield is maximized (Miller et al., 1962).

Berry size is probably indicative of grain yield unless soil N is so deficient that the number of kernels/head is decreased. Berry size was increased ($P < .05$) dramatically for the Redlan and Darset in year 1 suggesting that the basal level of N fertilization was inadequate for these two varieties (Table IX). Berry size was reduced substantially ($P < .05$) for the Darset in year 2 suggesting that factors other than N fertilization also interact to alter berry size. Percent protein can be altered by changes in berry size or changes in protein deposition (g/berry). Increased protein deposition (g/berry) was responsible for the changes in the Dwarf Redlan and 1133 in year 1 but an interaction between berry size and protein deposition appeared to be responsible for changes in year 2 (Table IX).

Protein deposition (g crude protein/100 berries) was increased ($P < .05$) by additional N for all varieties except the ROKY 78 in year 1

TABLE VIII. CHEMICAL COMPOSITION OF FERTILIZED SORGHUM GRAINS (DM BASIS)

Fertilized	Starch				Crude Protein				Tannin			
	Year 1[b]		Year 2[b]		Year 1[a]		Year 2[a]		Year 1[a]		Year 2[b]	
	o	+	o	+	o	+	o	+	o	+	o	+
	% of dry matter								catechin equivalents/g DM			
Dwarf Redlan	67.4	66.0	58.6	55.9	12.85 *	13.78	12.42 *	12.99	.06	.04	.19	.05
1133	63.1	64.1	56.0	57.2	13.16 *	14.08	12.00 *	11.40	.91	.88	3.38	3.10
Redlan	64.6	65.3	64.3	60.1	14.87	14.69	9.80 *	11.23	.05	.04	.06	.08
ROKY 78	64.3	64.1			12.78	12.83			1.00	.92		
Darset	65.5	65.7	57.2	56.9	14.17	14.32	12.85 *	13.46	1.41 *	.54	3.50	3.41
Mean	65.0	65.0	59.0	57.5								
SE[c]		1.2		2.6		.09		.09		.03		.13

*Significant fertilization level effect ($P<.05$).

[a]Significant variety x fertilization level interaction ($P<.05$).

[b]Fertilization level not significant ($P>.05$).

[c]Standard error of variety x fertilization level mean (2 obs./mean).

TABLE IX. BERRY SIZE, STARCH AND PROTEIN DEPOSITION OF FERTILIZED SORGHUM GRAINS

Fertilizer	Berry Size				Starch Deposition				Crude Protein Deposition			
	Year 1[a]		Year 2[a]		Year 1[a]		Year 2[a]		Year 1[a]		Year 2[a]	
	o	+	o	+	o	+	o	+	o	+	o	+
	-g/100 berries-											
Dwarf Redlan	3.089	3.118	2.623 *	2.307	2.081	2.058	1.537 *	1.290	.397 *	.430	.326 *	.300
1133	2.639 *	2.797	2.118	2.092	1.666 *	1.793	1.185	1.198	.347 *	.394	.254	.238
Redlan	2.518 *	3.462	2.197	2.330	1.626 *	2.260	1.413	1.399	.374 *	.509	.215 *	.262
ROKY 78	3.481 *	3.324			2.239 *	2.131			.445 *	.426		
Darset	2.513 *	3.010	2.236 *	1.799	1.645 *	1.978	1.279 *	1.024	.356 *	.431	.287 *	.242
SE[b]		.038		.059		.025		.035		.005		.007

*Significant fertilization level effect (P<.05).

[a]Significant variety x fertilization level interaction (P<.05).

[b]Standard error of variety x fertilization level mean (3 obs./mean).

(Table IX). In year 2, protein deposition was increased ($P < .05$) for the Redlan only and decreased ($P < .05$) for the Dwarf Redlan and Darset. Increased protein deposition for the Dwarf Redlan and 1133 in year 1 and the Redlan in year 2 were primarily due to increases in percent protein (Table VIII). In contrast, increased protein deposition for the Redlan and Darset sorghums in year 1 was due to significant increases in berry size (Table IX). Increased protein deposition in sorghum may occur in a sequence of two steps:

(1) berry size (yield) is increased until a maximum is reached and then,

(2) increased protein is deposited without further increases in berry size (Wall and Ross, 1970). The first step is necessary to maximize dry matter yield. Beyond this point, additional protein deposition is deposited in the protein matrix and may interfere with starch digestion.

The reason for the decrease in berry size and subsequent protein deposition for the Dwarf Redlan and Darset in year 2 is unclear. Perhaps the levels of other required nutrients were inadequate to maximize yield at the level of N applied. Alternatively, large quantities of available N may have precipitated a nutrient imbalance in the sorghum plant that decreased berry size.

Starch content (%) was unaffected ($P < .05$) by N fertilization in either year (Table VIII). As expected, starch deposition (g/100 berries) increased with berry size in both years (Table IX). Because starch is the largest component of the sorghum kernel, most of the increase in berry size is due to starch although other components increase as well.

Tannin content (catechin equivalents/g DM) of the Darset was

decreased ($P < .05$) by addition of N in year 1 (Table VIII). No other changes in tannin content attributable to N fertilization were observed. Even if tannin content (g/berry) was constant, a 20% increase in berry size could not account for the 3-fold reduction in tannin content. Whether or not the decreased tannin level for the Darset in year 1 is due to N fertilization or some other factor is unclear.

The addition of N fertilizer did not affect the protein composition (%) of any sorghum variety in either year (Table X). Small changes such as increased ($P < .05$) albumin and globulin (Fraction I) content for the Darset in year 1 and the 1133 in year 2 were observed. The only generalized effect was a slight decrease ($P < .05$) in glutelin-like (Fraction IV) protein in both years.

Deposition (mg/100 berries) of each protein fraction was altered by N application (Table XI). When N increased percent protein but not berry size (Dwarf Redlan and 1133 in year 1 and Redlan in year 2), the deposition of kafirin and glutelin protein increased ($P < .05$). Elevated kafirin deposition, however, resulted from increased ($P < .05$) kafirin (Fraction II) deposition for the 1133 (year 1) but increased ($P < .05$) kafirin-like (Fraction III) protein deposition was responsible for the Dwarf Redlan (year 1) and Redlan (year 2). In other cereal grains, N fertilization appears to increase glutelin and especially prolamine deposition (Munck, 1964; Eggum, 1977). Increased kafirin deposition is probably responsible for decreased protein quality of highly fertilized sorghum grain (Waggle et al., 1967).

When N fertilization increased berry size and percent protein remained constant (Redlan and Darset in year 1), increased protein deposition was noted in all fractions except glutelin-like protein

TABLE X. LANDRY-MOUREAUX PROTEIN COMPOSITION OF FERTILIZED SORGHUM GRAINS (% OF TOTAL CP)

	Fraction I				Fraction II				Fraction III				Fraction IV				Fraction V				Total Extracted			
	Year 1[a]		Year 2[a]		Year 1[b]		Year 2[b]		Year 1[b]		Year 2[b]		Year 1		Year 2		Year 1[b]		Year 2[b]		Year 1		Year 2	
Fertilized	o	+	o	+	o	+	o	+	o	+	o	+	o	+	o	+	o	+	o	+	o	+	o	+
	-% of total crude protein-																							
Dwarf Redlan	16.0	14.9	11.6	12.6	11.7	11.2	7.7	9.4	24.2	24.7	25.7	26.2	6.2	5.9	7.5	6.4	35.2	36.6	41.6	41.9	93.3	93.3	94.1	96.5
1133	11.0	10.4	4.7 *	7.1	11.4	13.2	6.9	6.4	20.9	19.1	17.5	16.2	8.5	6.9	15.6	14.4	43.7	41.4	51.2	53.9	95.5	91.0	95.9	98.0
Redlan	12.9	13.4	15.3	14.2	17.5	18.8	9.0	9.0	25.9	23.5	24.0	25.0	4.4	4.7	6.6	6.3	34.0	34.4	40.3	39.9	94.7	94.8	95.2	94.4
ROKY 78	10.6	11.1			13.1	13.3			19.3	19.6			7.0	6.8			43.3	44.0			93.3	94.8		
Darset	6.4 *	9.2	2.2	2.5	19.4	21.1	10.0	8.8	18.1	20.6	20.7	19.5	9.7	7.4	16.3	16.4	38.0	35.1	49.6	53.8	91.6	93.4	98.8	101.0
Mean					14.6	15.5	8.4	8.4	21.7	21.5	22.0	21.7	7.2 *	6.3	11.5 *	10.9	38.8	38.3	45.7	47.4	93.7	93.5	96.0	97.5
SE[c]		.5		.4		1.2		1.1		1.6		.9		.5		.3		1.1		2.3				

*Significant fertilization level effect ($P < .05$).

[a]Significant variety x fertilization level interaction ($P < .05$)

[b]Fertilization level was not significant ($P > .05$).

[c]Standard error of variety x fertilization level mean (2 obs./mean).

TABLE XI. LANDRY-MOUREAUX PROTEIN FRACTION DEPOSITION IN FERTILIZED SORGHUM GRAINS

	Fraction I				Fraction II				Fraction III				Fraction IV				Fraction V			
	Year 1[a]		Year 2[a]		Year 1[a]		Year 2[a]		Year 1[a]		Year 2[a]		Year 1[a]		Year 2[a]		Year 1[a]		Year 2[a]	
Fertilization	o	+	o	+	o	+	o	+	o	+	o	+	o	+	o	+	o	+	o	+
	mg protein/100 berries																			
Dwarf Redlan	63.4	64.0	37.7	37.9	46.5	48.2	25.2 *	28.2	96.0	106.0	83.7 *	78.4	24.8	25.2	24.6 *	19.2	139.6 *	157.0	135.6 *	125.6
1133	38.1 *	40.9	12.0 *	16.9	39.5 *	51.9	17.4 *	15.3	72.6	75.1	44.5 *	38.7	29.4 *	27.3	39.6 *	34.4	151.6 *	163.1	130.3 *	128.5
Redlan	48.2 *	68.2	32.9 *	37.2	65.5 *	95.7	19.3 *	23.4	96.9 *	119.4	51.8 *	65.5	16.6 *	23.7	14.3	16.4	127.5 *	174.8	86.9 *	104.5
ROKY 78	47.2	47.4			58.1	56.9			85.8	83.4			31.1 *	28.8			192.6	187.6		
Darset	22.8 *	39.6	6.4	6.0	69.2 *	91.0	28.6 *	21.2	64.4 *	88.6	59.4 *	47.2	34.4 *	31.8	46.8 *	39.8	135.3 *	151.1	142.6 *	130.2
SE[b]		.6		.8		.8		.6		1.1		1.6		.4		.7		2.0		3.1

*Significant fertilization level effect ($P < .05$).

[a]Significant variety x fertilization level interaction ($P < .05$).

[b]Standard error of variety x fertilization level mean (3 obs./mean).

(Fraction IV, Table XI). Thus, protein composition may be fairly constant until yield (berry size) is maximized. When berry size decreased, regardless of changes in percent protein (Dwarf Redlan and Darset in year 2), protein deposition generally decreased for all except the albumins and globulins (Fraction I). In barley, albumin and globulin content (mg/berry) changes very little with changes in berry size (Munck, 1964). Consequently, larger berries may have a lower percentage of albumin and globulin protein.

In vitro dry matter disappearance (IVDMD) was increased ($P < .05$) for the Darset variety only in year 1 but for all varieties in year 2 (Table XII). Increased berry size and/or decreased tannin content may explain the Darset response in year 1. In year 2, however, increased IVDMD was associated with elevated protein content (%). Eng et al. (1965) observed a positive correlation between protein content (%) and protein digestibility. Part of the increase in protein digestibility may be due to the fact that protein intake was equalized by manipulating dry matter intake. Some of the increase may be due to a true increase in protein digestibility. If, in fact, increased protein levels increase protein digestibility, the fear that increased kafirin or glutelin deposition may decrease starch availability through shrouding of starch granules is probably unfounded.

These studies suggest that the protein characteristics of sorghum grain can be altered dramatically by the addition of N fertilizer during growth. From a nutritional standpoint, N application can increase protein content although protein quality (% lysine) may be decreased. Increased percent protein does not appear to consistently hinder the in vitro digestibility of sorghum grain ($r = -.004$ in year 1 and $-.26$ in

TABLE XII. EIGHTEEN HOUR IVDMD OF FERTILIZED SORGHUM GRAINS

Fertilizer	Year 1[a]		Year 2	
	o	+	o	+
	---------- % ----------			
Dwarf Redlan	61.2	61.7	58.9	62.5
1133	53.7	51.3	46.5	52.9
Redlan	56.0	56.0	53.8	58.0
ROKY 78	52.3	50.5		
Darset	49.4	53.7	39.4	44.6
Mean			49.6 *	54.5
SE[b]		1.0		.8

*Significant fertilization level effect ($P < .05$).

[a]Significant variety x fertilization level interaction ($P < .05$).

[b]Standard error of variety x fertilization level mean (4 obs./mean).

year 2, both $P > .5$). In fact, digestibility and even growth rate of ruminants may be increased. Nitrogen fertilization of wheat and barley increased weight gains in rats, especially with the addition of lysine (McBeath et al., 1960; Bhatty et al., 1963).

From an agronomic standpoint, additional N stimulates dry matter yield up to a certain level. Further addition of N can increase protein content of the grain and protein yield per hectare. Nutritionally, this effect appears to be beneficial so that the only limiting factor is the economic return of increased N application.

CHAPTER IV

THE EFFECT OF STAGE OF MATURITY ON CHEMICAL COMPOSITION AND IVDMD OF DIVERGENT SORGHUM GRAIN VARIETIES

Summary

Waxy (Dwarf Redlan), waxy bird resistant (1133), normal (Redlan) and normal bird resistant (Darset) varieties of sorghum grain were harvested at weekly intervals starting five weeks preharvest (58 to 79% dry matter (DM)) in year 1 and eight weeks preharvest (35% DM) in year 2 to determine the effect of maturity on chemical composition and IVDMD of the grain. Grain samples were immediately threshed, ground (1 mm screen) and evaluated. Physiological maturity, measured by dry matter deposition (g/berry), was essentially complete by the time the grain reached 70% DM. The Darset (BR=bird resistant) appeared to reach physiological maturity somewhat earlier (65% DM). At 70% DM in year 2, there was a range of 17 days in age, suggesting that the Darset and 1133, both BR varieties, dried substantially faster than the Dwarf Redlan and Redlan non-BR types. Starch, expressed as a percent of DM, increased through about 55 to 60% DM, although when measured as g/berry, starch deposition continued to increase through 70% DM. Starch deposition beyond 55% DM is probably a reflection of increased berry size. Percent protein and ash decreased through maturity, although the g of protein per berry increased through about 70% DM. Starch and protein deposition

increased linearly with berry size, but starch deposition occurred at a faster rate than protein. Soluble protein (NaCl) decreased and pepsin insoluble protein (PIN) generally increased through maturity, indicative of glutelin and kafirin deposition. Tannin content of the BR sorghums decreased rapidly through 70% DM and continued to decrease, although more slowly, through harvest. In vitro dry matter disappearance (IVDMD) decreased throughout maturity, especially in year 2. Varietal differences in certain parameters, notably soluble protein and IVDMD, were negligible early in maturity (35% DM), but had expanded dramatically by harvest. Varietal differences in other parameters, such as PIN, were similar throughout maturity. These studies suggest that dramatic changes in the absolute and relative concentration of various sorghum kernel components occur before and through physiological maturity. Furthermore, these changes appear to be highly variety dependent which may alter the results obtained with different high moisture harvested sorghum grains.

Introduction

Increased energy costs for processing sorghum grain have motivated cattle feeders to consider processing systems which are more energy efficient than steam flaking or micronizing. High moisture methods (reconstitution or high moisture harvest) require less energy than steam flaking and can produce similar animal performance (Hale and Prouty, 1980; Mies and Summers, 1980). In order to fully exploit the potential of high moisture processed grain, specifically high moisture harvested grain, the effects of several factors must be more fully understood. For example, moisture level and storage time can significantly alter the feeding value and digestibility of high moisture corn (Thornton et al.,

1969b; Prigge et al., 1976). Similar effects are probably true for sorghum grain although harvest at moisture levels above 30% may be more critical (Neuhaus and Totusek, 1971).

One factor that has been neglected in high moisture sorghum studies is the effect of variety or endosperm type. Large differences exist in the chemical composition and IVDMD of different varieties of mature sorghum grain (Miller et al., 1972; Hibberd, 1979). These differences may be preceded by differences throughout maturity and may affect the feeding value of high moisture harvested grain. Concentrations of various chemical components (starch, protein, ash) change throughout maturation of corn and sorghum grain (Kersting et al., 1961; Thornton et al., 1969a; Danley and Vetter, 1974a,b). Most cereal grains reach physiological maturity (maximum dry matter deposition) between 60 and 70% dry matter (Shaw and Thom, 1951). Physical characteristics of starch, protein or even tannin may continue to change through harvest (Misra and Mertz, 1975; Boyer et al., 1976; Davis and Hoseney, 1979). But changes in the concentration and relative composition of these constituents with maturity have not been characterized for widely differing sorghum grain varieties. In addition, the effect of these changes on the digestibility of sorghum grain are unknown. The objectives of this study were to:

(1) monitor maturational changes in the deposition of various kernel constituents in several widely divergent varieties of sorghum grain, and

(2) evaluate changes in chemical composition by <u>in vitro</u> dry matter disappearance.

Materials and Methods

Waxy (Dwarf Redlan), normal (Redlan) and normal bird resistant (Darset) varieties of sorghum grain were grown in adjacent plots under similar conditions at the Southwest Livestock and Forage Research Station El Reno, OK in year 1 (Table XIII). These three varieties plus a waxy bird resistant variety (1133) were grown at the Agronomy Research Station Perkins, OK in year 2. Six heads representative of each variety selected at random were harvested at weekly intervals for five weeks starting September 9 in year 1 and for eight weeks starting August 28 in year 2. Sorghum heads were immediately threshed and intact kernels manually separated from chaff. Berry size was estimated by weighing triplicate groups of 100 whole kernels. Grain samples were ground with dry ice through a 1 mm screen in a laboratory Wiley mill. Samples were frozen immediately (-5 C) to minimize drying and fermentation and stored for analysis.

Crude protein (N X 6.25) was analyzed by Kjeldahl (AOAC, 1975) and starch content as α-linked glucose polymers following enzymatic degradation (MacRae and Armstrong, 1968). Percent starch and protein was multiplied by berry size (g/100 berries) to obtain amounts of starch and protein per kernel (g/berry). Tannin content was measured as catechin equivalents using a vanillin-HCl procedure (Burns, 1971) modified by Price et al. (1978). Ash content was estimated after combustion of organic material at 500 C. Changes in protein solubility were monitored by nitrogen solubilization in .15 M NaCl (Waldo and Goering, 1979). Protein indigestibility was measured as pepsin insoluble nitrogen (Goering and Van Soest, 1970). Changes in relative digestibility were evaluated with an 18-h single stage *in vitro* dry matter disappearance

TABLE XIII. DESCRIPTIVE CHARACTERISTICS OF SORGHUM GRAIN VARIETIES

Variety	Seed Coat Color	Endosperm		Classification
		Color	Starch	
Dwarf Redlan	Red	White	Waxy	Waxy
1133[b]	Brown	Yellow	Waxy	Waxy - BR[a]
Redlan	Red	White	Normal	Normal
Darset	Brown	White	Normal	Normal - BR[a]

[a]BR = Bird resistant.

[b]Year 2 only.

technique using inoculum from a steer fed an 80% concentrate diet (Hibberd, 1979). Urea (20 mg/tube) was added to satisfy fermentable nitrogen requirements.

Standard errors for variety X day or dry matter means within each year were calculated from the residual mean square entry of an analysis of variance table that accounted for variation due to variety, run (IVDMD only), day or dry matter and linear and quadratic effects of day or dry matter.

Results and Discussion

Grain grown in year 1 received very little precipitation during the growing season when compared to year 2 (Figure 3). Dry matter content increased throughout maturity except when rainfall slowed drying (Figure 4). Lower initial dry matter content of year 2 sorghums is a reflection of earlier sampling dates. Darset reached 70% DM about 17 days earlier than the Redlan. As grain matured, berry size (g/100 kernels) increased until the grain was about 70% DM suggesting that physiological maturity (maximum dry matter deposition) was complete at this point (Figure 4). In year 1, Redlan and Darset varieties reached physiological maturity before sampling was initiated. Physiological maturity occurred around 64% DM for the Darset in year 2 suggesting that this variety could be harvested earlier than other sorghums without sacrificing dry matter yield.

Starch

Percent starch increased through 50 to 55% DM for all but the Redlan in year 2 (Figure 5). The Redlan peaked somewhat later (65% DM).

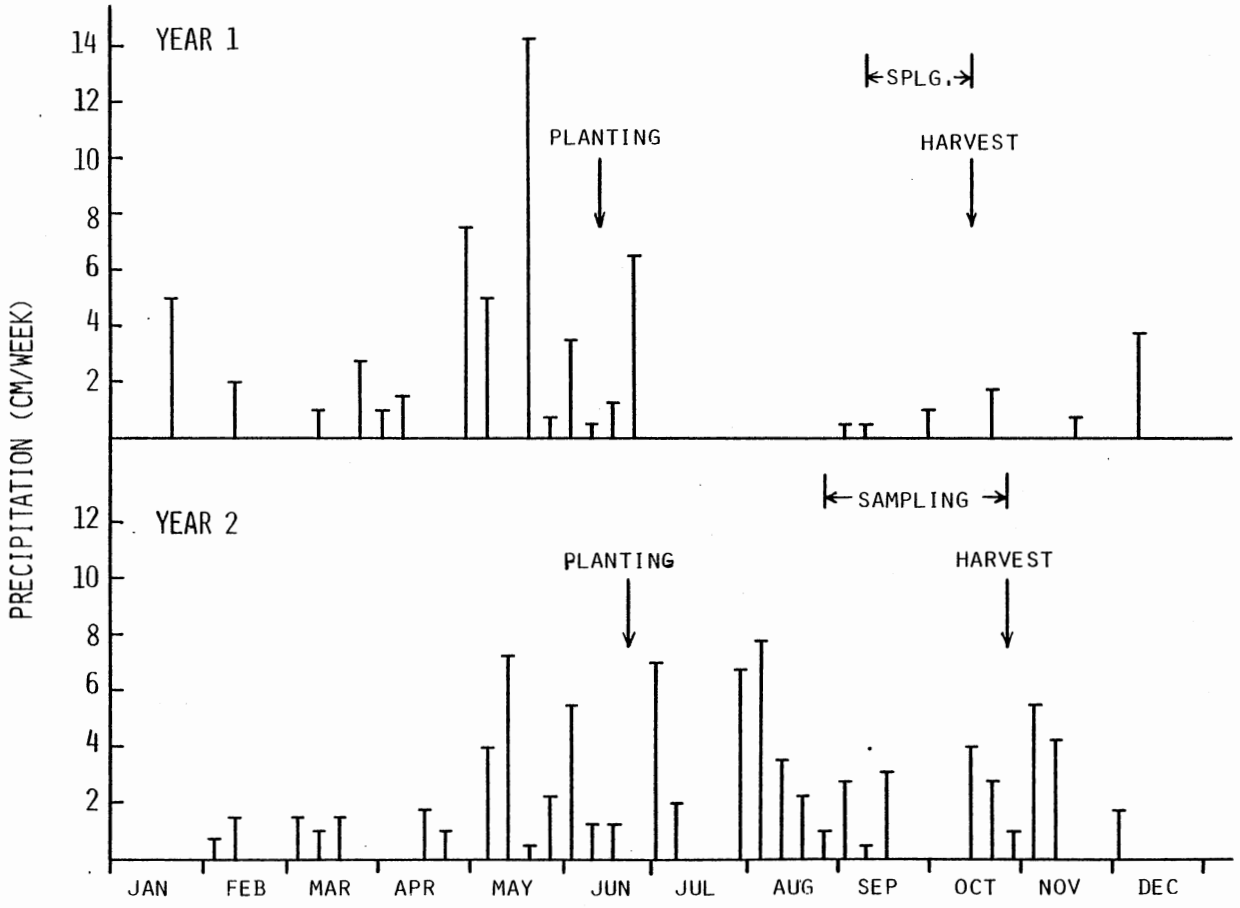


Figure 3. Rainfall profiles, planting, harvesting and sampling dates.

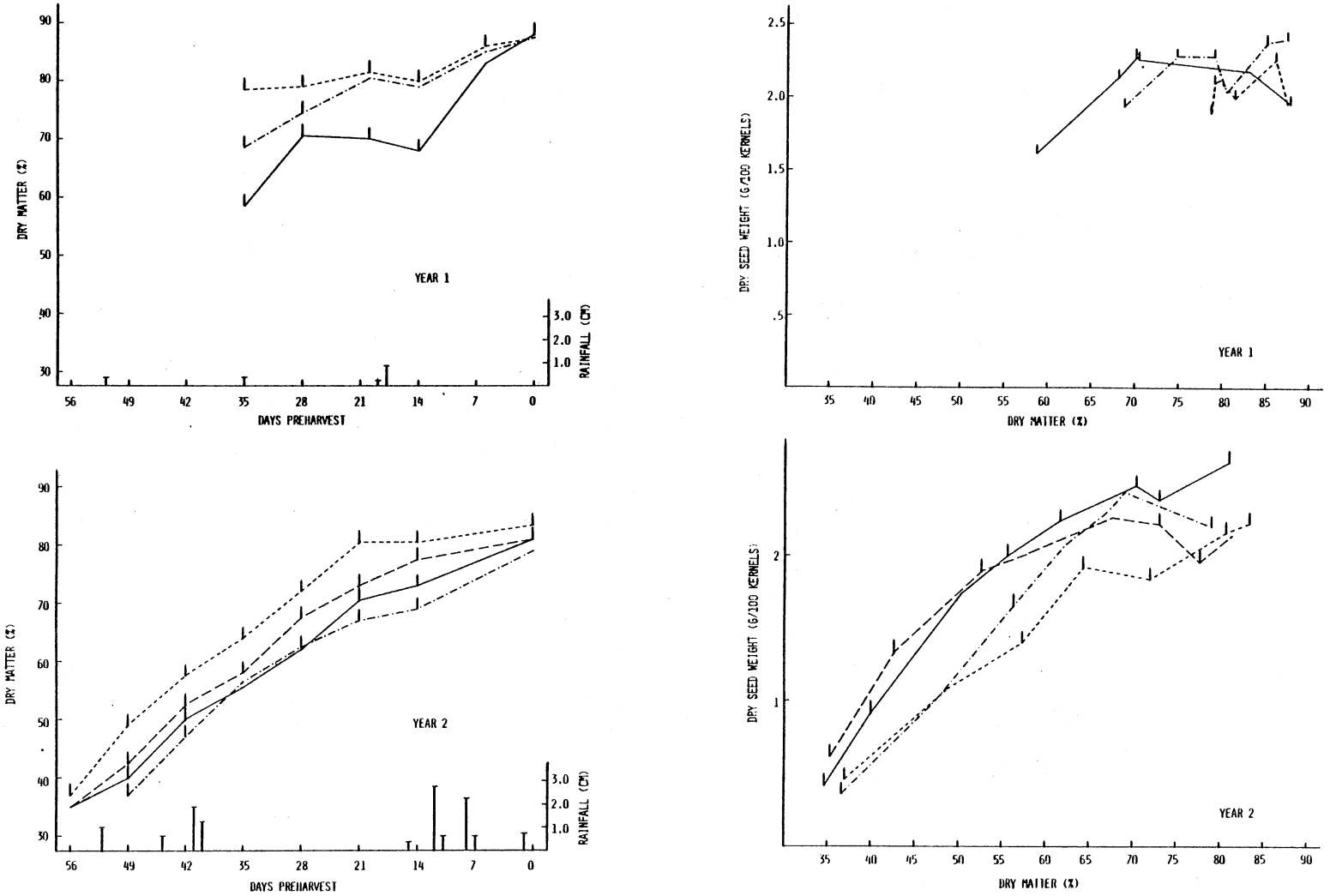


Figure 4. Dry matter content and berry size of maturing sorghum grain (——— Dwarf Redlan, — — 1133, —·—·Redlan, - - - - Darset).

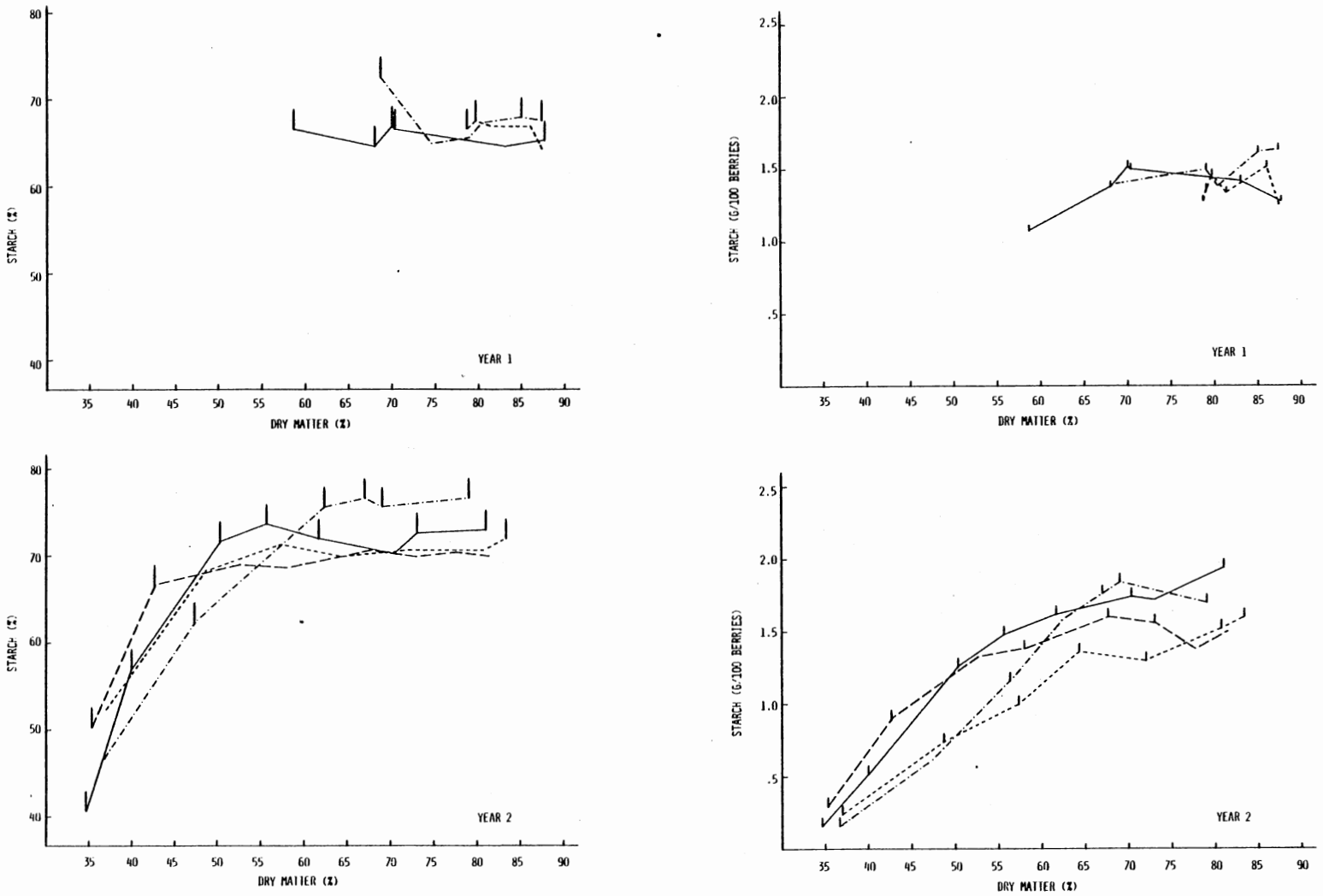


Figure 5. Starch content (%) and deposition (g/100 berries) of developing sorghum grains (——— Dwarf Redlan, — — 1133, —·—·Redlan, - - - - Darset).

This explains the uniformity in starch content observed in year 1. Kersting et al. (1961) observed that starch content (%) of sorghum grain peaked about 30 to 40 days after pollination, similar to the time-span observed in the present study. Starch deposition (g/berry) in year 2 continued to increase through about 70% DM which coincided with the peak in berry size (Figure 5). Increased starch deposition between 50 and 70% DM is probably a reflection of increased berry size. Similar trends were observed in year 1. In a study with only one sorghum variety, percent starch and starch deposition (g/100 kernels) occurred simultaneously (Kersting et al., 1961). Environmental differences such as moisture level or air temperature may alter the growth rate and nutrient deposition in sorghum grain (Heller and Sieglinger, 1944).

Protein

Percent protein (N X 6.25) generally decreased through 55 to 60% DM for all varieties in year 2 (Figure 6). Although somewhat variable, protein content (%) of the Darset may have plateaued earlier (50 to 55% DM). Similar to starch deposition, however, protein deposition (g/berry) continued to increase through 65 to 70% DM for the Dwarf Redlan in year 1 and all varieties in year 2 (Figure 6). In both corn and sorghum, nitrogen content (%) appears to decrease rapidly through the first 20 days after pollination and remains steady thereafter (Kersting et al., 1961; Misra and Mertz, 1975). Nitrogen deposition peaked approximately 20 days later, about the same time as starch (Kersting et al., 1961).

Starch vs. Protein Deposition

Protein deposition (g/berry) increased linearly ($P < .0001$) as

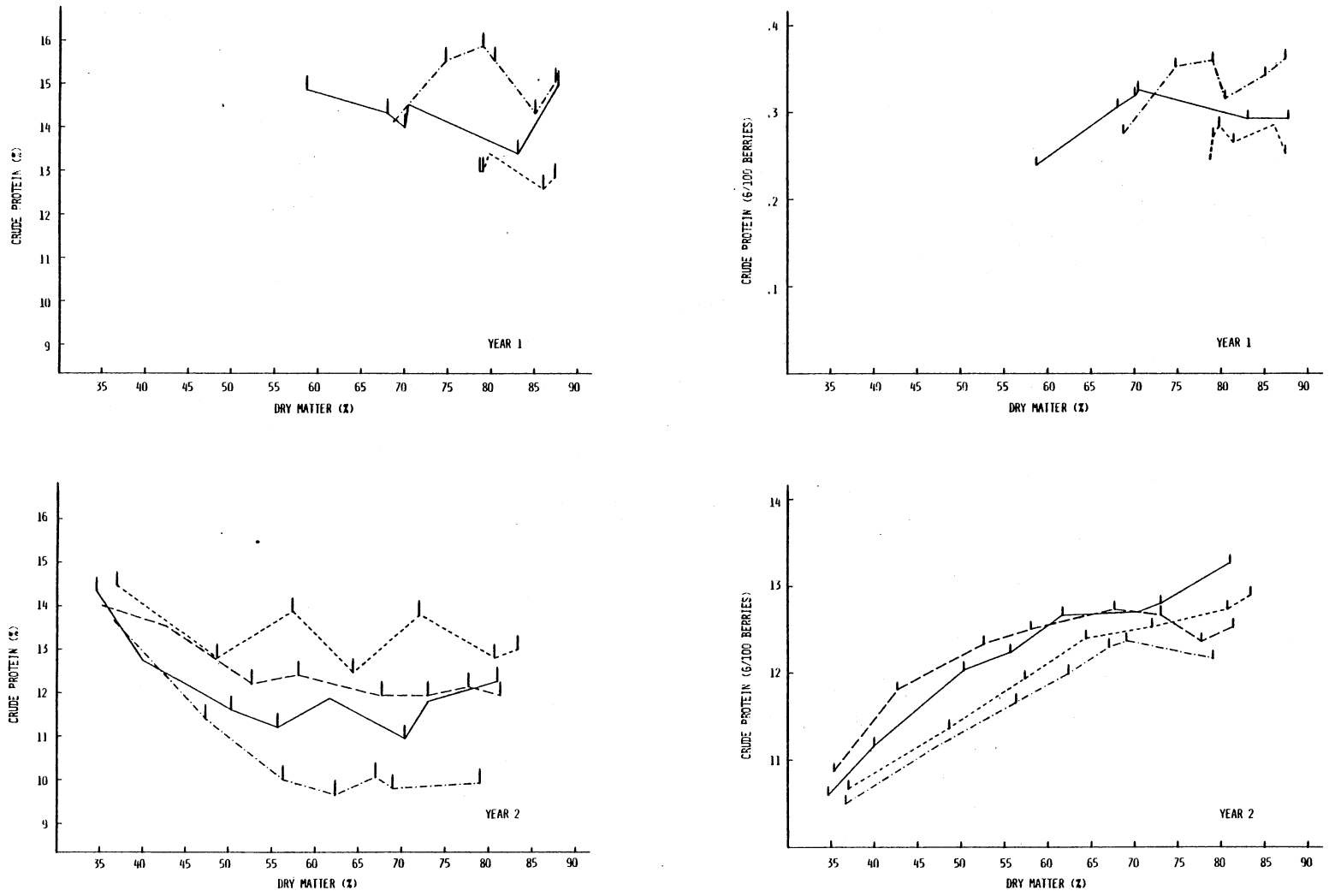


Figure 6. Crude protein (%) and deposition (g/100 berries) of maturing sorghum grain (——— Dwarf Redlan, — — 1133, —·—·Redlan, - - - - Darset).

starch deposition (g/berry) increased (Figure 7). For each g increase in starch deposition, protein deposition increased .133 g in year 2. Although starch and protein are probably deposited at different rates, the ratio between the two appears to be fairly constant. Protein deposition relative to starch deposition was greater in year 1 than in year 2. Although the data set in year 1 is smaller, different environmental factors such as rainfall or nitrogen fertilization could alter the rate and quantity of either protein or starch deposition.

Protein Characteristics

Salt (NaCl) soluble protein (%) decreased through 65 to 70% DM (Figure 8). The bird resistant sorghums (1133 and Darset) always contained less soluble protein than either the Dwarf Redlan or Redlan. Highly soluble proteins (albumins and globulins) associated with the pericarp and cell wall structure are probably deposited early (Wall and Ross, 1970; Misra and Mertz, 1975). As the kernel continued to mature, matrix protein (glutelin) was deposited along with kafirin, the storage protein in sorghum grain (Misra and Mertz, 1975). Continued deposition of kafirin, which is very low in lysine, is probably responsible for the decrease in protein quality that occurs as sorghum grain matures (Deyoe et al., 1970). Glutelin and especially kafirin are relatively insoluble proteins that resist ruminal attack (Walker and Lichtenwalner, 1977). Although not dramatic, pepsin insoluble nitrogen increased for the Dwarf Redlan and Redlan, especially beyond 55 to 60% DM (Figure 8). This effect is probably due to drying and compaction of protein constituents through the final stages of maturity. In contrast, the pepsin insoluble nitrogen content of the bird resistant sorghums appeared to

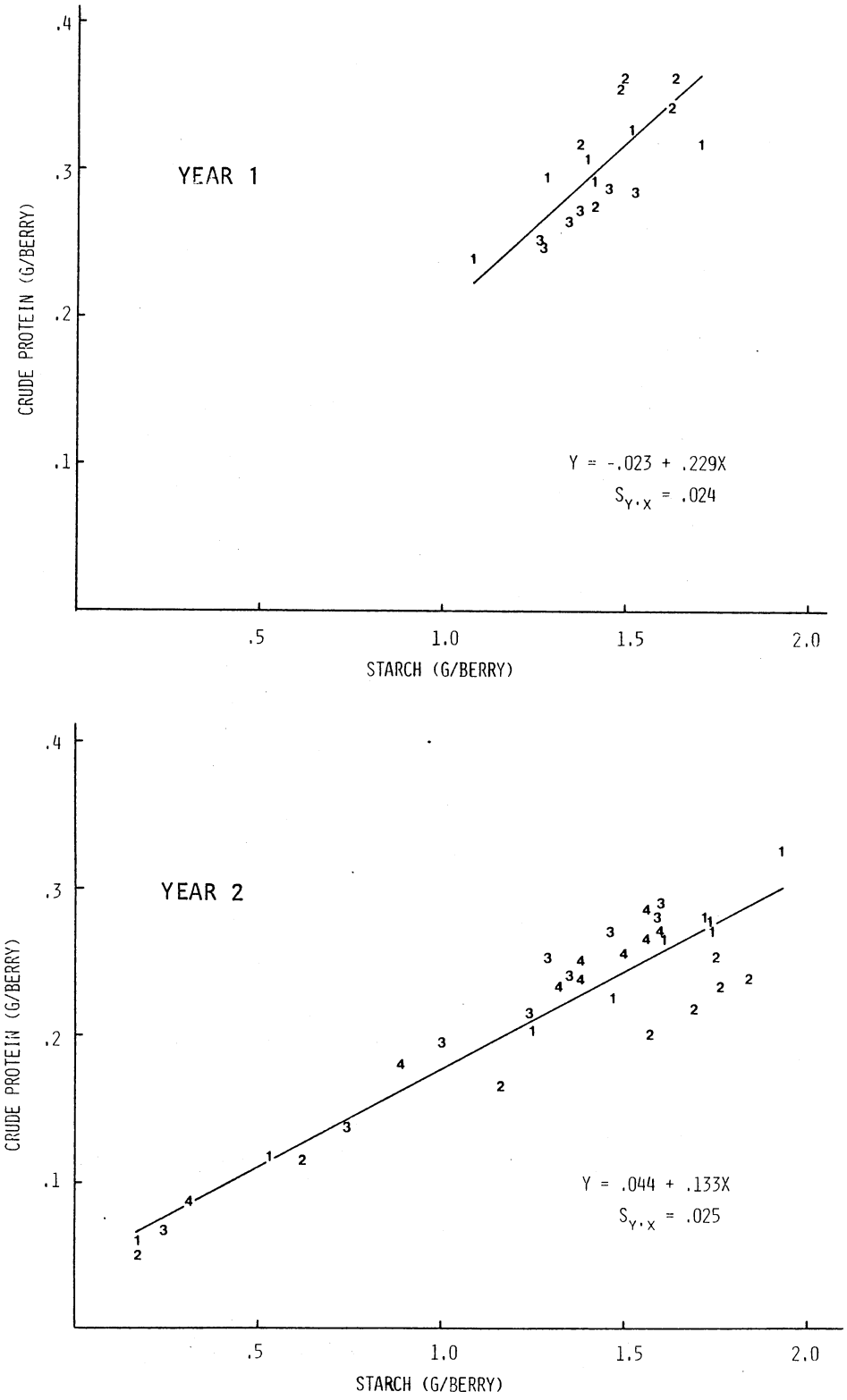


Figure 7. Starch vs. protein deposition (1 = Dwarf Redlan, 2 = Redlan, 3 = Darset, 4 = 1133).

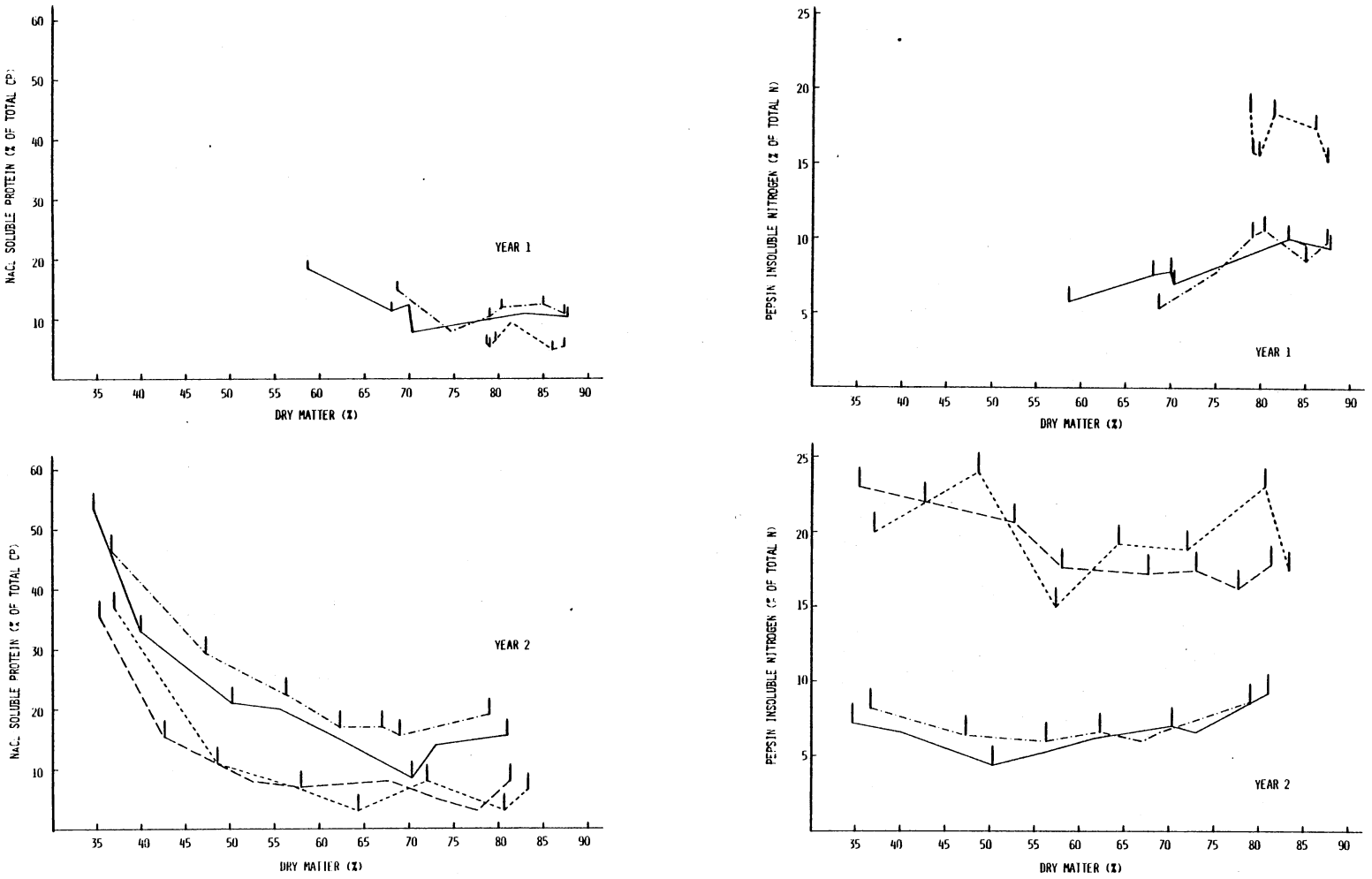


Figure 8. Salt (NaCl) soluble and pepsin insoluble protein content of maturing sorghum grain varieties (——— Dwarf Redlan, — — 1133, —·—· Redlan, - - - - Darset).

decrease, especially in early maturity. Changes in other kernel constituents, such as reduced tannin, may be responsible for increased pepsin solubility (Davis and Harbers, 1979).

Ash and Tannin

Similar to protein, ash concentration decreased through maturity (Figure 9). Ash concentration stabilized around 65 to 70% DM, somewhat later than protein concentration. The concentrations of several minerals especially potassium and calcium, decreased through maturity for wheat, rye and triticale (Lorenz and Reuter, 1976). Tannin content (catechin eq./g) increased rapidly for the Darset in early maturity in year 2 (Figure 9). Tannin content of the 1133 had begun to decline from a peak at this point. Both bird resistant varieties decreased in tannin concentration through about 60% DM after which tannin concentration remained relatively constant. Several studies have illustrated that tannin content decreases as bird resistant sroghums mature (Davis and Hoseney, 1979; Price et al., 1979). Glennie (1981) reported that most of the decrease in tannin content early in maturity was due to loss or polymerization of low molecular weight phenolic compounds that have little protein binding capacity relative to the condensed tannins found in mature grains. High tannin content early in maturity may serve to discourage bird predation when the sorghum kernel is young, immature and succulent.

In Vitro Dry Matter Disappearance

In vitro dry matter disappearance (IVDMD) decreased as maturity progressed for all varieties in year 2 (Figure 10). The decrease in

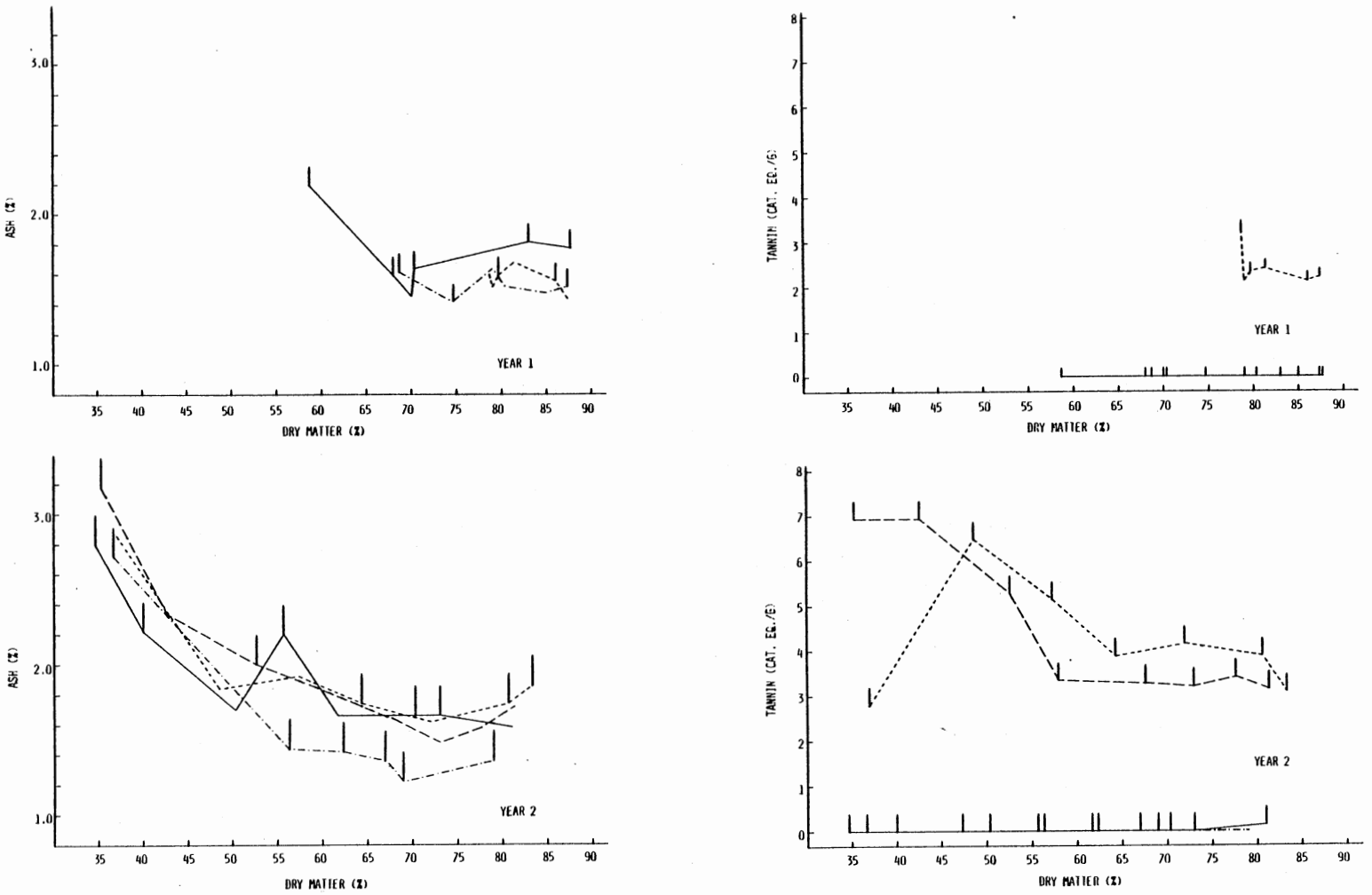


Figure 9. Ash and tannin content of developing sorghum grain varieties (——— Dwarf Redlan, — — 1133, —·—·Redlan, - - - - Darset).

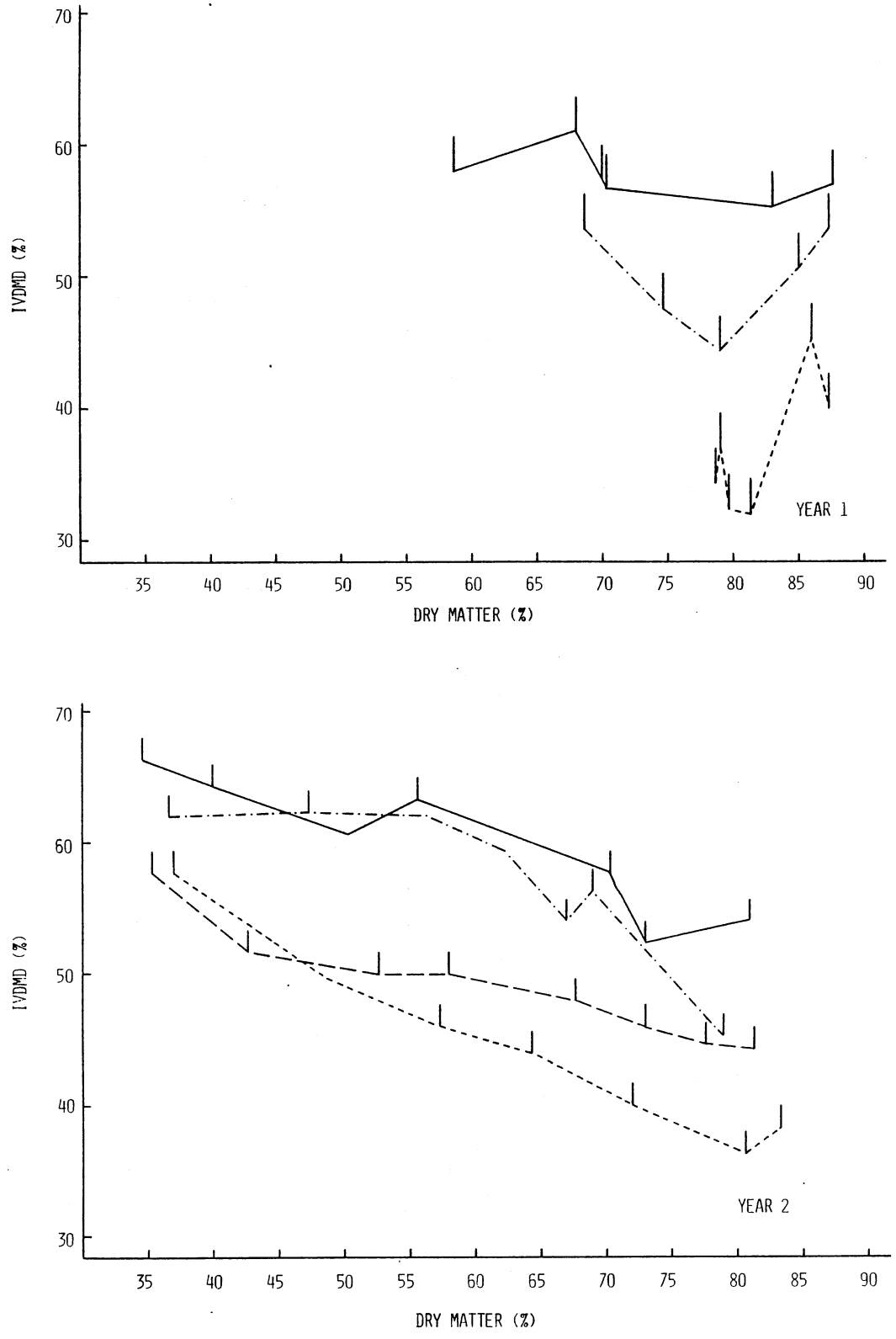


Figure 10. IVDMD of maturing sorghum grain varieties (——— Dwarf Redlan, — — 1133, —·—·Redlan, - - - - Darset).

IVDMD was most dramatic for the Redlan and Darset varieties. Some of this decrease is probably due to a decrease in soluble protein and increased matrix protein deposition and complexing of mature starch granules. In addition, the amylose content of starch increases with maturity which may render the starch less susceptible to enzymatic attack (Leach and Skoch, 1961; Boyer et al., 1976). Dehydration and compaction of structural components such as matrix protein and/or cell wall material may further decrease IVDMD.

High tannin content of the bird resistant sorghums early in maturity appears contradictory with the high IVDMD at this time (Figure 10). Large concentrations of low molecular weight phenols with little protein binding ability may have inflated the measurement of tannin content (Glennie, 1981). Low molecular weight phenolics polymerize throughout maturity to form more efficient protein binding complexes (Reichert et al., 1980). Thus, a high tannin content of immature grain may not decrease IVDMD.

In vitro digestibility was slightly greater (average 11.6%) at 70% DM than at maturity (Figure 10). Larger differences in IVDMD between sorghum grain harvested and ensiled at 30% moisture vs. 13% moisture than observed in the present study probably illustrate the importance of fermentation (Neuhaus and Totusek, 1971). Fermentation of high moisture harvested grain may not only preserve but may increase feeding value of sorghum grain.

Discussion

Relative proportions of various sorghum kernel constituents change substantially with stage of maturity. Percent starch increases while

percent protein and ash decrease through physiological maturity. Growth in berry size was primarily from increased deposition (g/berry) of protein and starch. Physiological maturity, as measured by dry matter deposition, was usually reached around 70% DM. Certain varieties, such as the Darset, may reach physiological maturity at lower dry matter (60% DM) indicating that some varieties may be harvested earlier than others without a reduction in yield.

Substantial differences in the chemical composition of each variety were observed at any given stage of maturity. For some components, such as crude protein, differences were very small early in maturity (35% DM) but increased by physiological maturity. Varietal differences in other components such as soluble protein, however, were maintained throughout maturity. Consequently, the relative composition of developing sorghum grain is highly dependent on the variety and the component of interest.

Amounts of various components change, even after physiological maturity. Soluble protein and tannin decreased while pepsin insoluble nitrogen increased as sorghum progressed from 70% DM through harvest. These changes may be related to the dehydration and compaction that occurs as the grain dries.

Most high moisture grain is harvested between 65 and 70% dry matter. Although digestibility (IVDMD) decreased throughout maturity, our studies reinforce the premise that the grain must reach 65 to 70% DM in order to maximize dry matter yield. Harvest of certain varieties (Darset) may be initiated slightly earlier with adequate yield. These studies also indicate that different sorghum varieties vary substantially in chemical composition at various stages of maturity. More complete

understanding of varietal effects should permit enhanced utilization of high moisture sorghum.

CHAPTER V

EFFECT OF VARIETY AND LENGTH OF RECONSTITUTION ON CHEMICAL COMPOSITION AND IVDMD OF SORGHUM GRAIN

Summary

Waxy (Dwarf Redlan), waxy bird resistant (1133), normal (Redlan) and normal bird resistant (Darset) varieties of sorghum grain were grown and harvested under similar conditions for two consecutive crop years to determine the effect of variety and length of reconstitution on chemical composition and IVDMD of sorghum grain. Dry grain samples (whole berries) were ground or reconstituted by increasing the moisture level to 30% and storing under anaerobic conditions for varying lengths of time varying from 1 to 21 days. Reconstitution for 21 days increased ($P < .05$) *in vitro* dry matter disappearance (IVDMD) of the Darset to a much greater degree than other sorghums in both years (29% increase in year 1 and 55% in year 2). In year 2, reconstitution increased the IVDMD of the 1133 and Redlan varieties as well, but not to the same extent. The potential response to reconstitution appears dependent on initial chemical composition. Darset generally contained the least NaCl soluble protein and the most pepsin insoluble nitrogen (PIN) and tannin content. Reconstitution decreased PIN and tannin content and increased IVDMD within two to four days. Changes in starch, crude protein and NaCl soluble protein were generally small and insignificant as reconstitution

progressed. Short-term (3 to 5 day) reconstitution may have potential as a rapid, inexpensive method of increasing the nutritive value of bird resistant sorghum grain. In addition, the speed with which many of the changes in chemical composition and IVDMD occur suggests that shorter storage periods (< 21 days) may be satisfactory. Shorter reconstitution periods would increase the feasibility of this process for large feedlots.

Introduction

Addition of water to dry whole sorghum grain and storage under anaerobic conditions for 21 days (reconstitution) is an efficient and nutritionally effective grain processing technique (Totusek et al., 1967; Newsom et al., 1968; White et al., 1969). Reconstituted sorghum grain has been shown to be similar to steam flaked grain for growth of feedlot cattle and may result in even better feed conversion (Hale and Prouty, 1980). Yet, response of sorghum grain to reconstitution varies considerably from one experiment to the next (Hinders, 1976). Although part of this variation may be attributable to differences in experimental conditions, all sorghum varieties may not respond equally to grain processing (Saba et al., 1972; Hibberd, 1979).

Certain varieties of sorghum grain may respond better than others because of unique differences in the chemical composition of the unprocessed grain. Much of the reconstitution response is probably attributable to disruption of the subcellular organization of the peripheral endosperm which increases starch accessibility (Sullins et al., 1971). Consequently, sorghum varieties containing a more extensive protein matrix may respond better to reconstitution. In addition,

reconstitution may destroy or inactivate the tannins in bird resistant sorghum either through germination or fermentation (Cummins, 1971; Reichert et al., 1980). The amount of protein matrix and/or tannins present in a certain variety also may affect the length of time required for the reconstitution process to be effective.

The reconstitution process should be more fully understood when changes in chemical constituents that occur during the process are characterized. Reasons for the variety dependent response also may be clarified. In addition, if changes in the chemical components of the kernel occur rapidly, shorter storage periods may provide increased turnover of grain stores for cattle feeders. The objective of this study was to evaluate changes in chemical composition and IVDMD of several varieties of sorghum grain as the grain progresses through a 21-day reconstitution period.

Materials and Methods

A waxy (Dwarf Redlan), normal (Redlan) and normal bird resistant (Darset) sorghums were grown and harvested under similar conditions at the Southwest Livestock and Forage Research Station, El Reno, OK in year 1 (Table XIV). A second group of the original three varieties plus a waxy bird resistant (1133) were obtained from identical plots at the Agronomy Research Station, Perkins, OK in year 2. Seventy grams (whole berries) of each variety were placed in 250-ml glass bottles with sufficient water added to raise the moisture level to 30%. The bottles were sealed and agitated frequently until all free water had been absorbed. Bottles were stored in the dark at 25 C and duplicate bottles removed on days 1, 2, 3, 4, 5, 7, 9, 12, 16 and 21 of incubation.

TABLE XIV. DESCRIPTIVE CHARACTERISTICS OF SORGHUM GRAIN VARIETIES

Variety	Seed Coat Color	Endosperm		Classification
		Color	Starch	
Dwarf Redlan	red	white	waxy	waxy
1133[b]	brown	yellow	waxy	waxy - BR[a]
Redlan	red	white	normal	normal
Darset	brown	white	normal	normal - BR[a]

[a]BR = Bird resistant.

[b]Year 2 only.

Duplicate bottles were composited and ground through a 20-mesh (1 mm) screen in a laboratory Wiley mill with the aid of dry ice. Samples were stored at -5 C until analysis.

Crude protein (N X 6.25) was determined by Kjeldahl (AOAC, 1975) and starch content as α-linked glucose polymers, following enzymatic degradation of starch (MacRae and Armstrong, 1968). Tannin content was measured as catechin equivalents using a vanillin-HCL procedure (Burns, 1971) as modified by Price et al. (1978). Protein solubility was monitored by changes in salt (.15 M NaCl) soluble protein (Waldo and Goering, 1979). Protein indigestibility was measured as pepsin insoluble nitrogen (Goering and Van Soest, 1970). Hydrogen ion concentration (pH) was determined by soaking 5 g of whole berries in 5 ml of distilled water for 30 minutes and measuring pH on a single electrode Corning 125 pH meter. Changes in dry matter digestibility were evaluated with an 18-h single stage in vitro dry matter disappearance technique (Hibberd, 1979). Twenty mg of urea were added to each tube to insure adequate fermentable N concentration.

Standard errors for variety X day means within each year were obtained from the residual mean square entry of an analysis of variance table that accounted for variation from variety, run (IVDMD only) and linear and quadratic effects of day. Significant differences between variety X day means were detected by t-test (Federer, 1967).

Results and Discussion

Physical properties and chemical composition of the dry, unprocessed sorghum grain varied significantly due to varietal and year effects (Table XV). For example, Redlan had the largest berries in year 1,

TABLE XV. CHEMICAL COMPOSITION OF DRY, UNPROCESSED SORGHUM GRAIN VARIETIES (DM BASIS)

Item	Year 1			Year 2			
	Dwarf Redlan	Redlan	Darset	Dwarf Redlan	1133	Redlan	Darset
Berry size (g/100 berries)	1.96[b]	2.41[a]	1.96[b]	2.65[a]	2.14[b]	2.20[b]	2.23[b]
Crude protein (%)	15.04[a]	15.09[a]	12.88[b]	12.30[b]	11.91[b]	9.91[c]	13.00[c]
NaCl soluble protein (% of total CP)	10.7	10.6	5.5	15.3[a]	8.2[b]	19.0[a]	6.6[b]
Pepsin insoluble protein (% of total CP)	9.5[b]	9.9[b]	15.2[a]	9.1[b]	17.8[a]	8.5[b]	17.4[a]
Starch (%)	65.4	67.7	64.4	73.3[ab]	69.9[b]	76.8[a]	71.9[b]
Ash (%)	1.77[a]	1.52[ab]	1.44[b]	1.58[ab]	1.72[a]	1.35[b]	1.86[a]
Tannin (cat. eq./g)	.00[b]	.00[b]	2.18[a]	.13[b]	3.13[a]	.00[b]	3.05[a]

[abc]Means within a year differ ($P < .05$).

[d]Dry matter basis.

while Dwarf Redlan was the largest in year 2. Crude protein content varied substantially across years (e.g. Redlan was 15.09% in year 1 vs. 9.91% in year 2). In addition, starch content was lower in year 1 than in year 2. More soluble (NaCl) protein was found in the Dwarf Redlan and Redlan varieties than in the bird resistant types. In contrast, bird resistant sorghums contained almost twice as much pepsin insoluble nitrogen as the nonbird resistant types. Bird resistant sorghums had elevated ($P < .05$) tannin content in both years although year 2 was about one unit higher than year 1.

Traditional 21-day reconstitution increased ($P < .05$) the IVDMD of the Darset in year 1 and all but the Dwarf Redlan in year 2 (Figure 11). Similar to results noted in a previous study (Hibberd, 1979), varieties with low IVDMD when dry ground were the most responsive to reconstitution. Bird resistant sorghums, especially the Darset, responded more dramatically than other sorghum types (waxy, normal). Bird resistant sorghums have been shown to respond better to steam flaking than red sorghums (Saba et al., 1972). Because the bird resistant sorghums responded well to processing, the range in IVDMD for reconstituted grain was much less than the range observed for unprocessed sorghum. Consequently, intensive processing techniques may result in increased uniformity of feeding responses when sorghum based rations are used.

The variety with the least soluble protein, the most insoluble protein and the greatest tannin content (Darset) responded most dramatically to reconstitution (Table XV). Reconstitution appears to disrupt the proteinaceous network of the sorghum endosperm (Sullins et al., 1971). Consequently, varieties with unfavorable protein characteristics might be expected to respond the most to reconstitution. In addition,

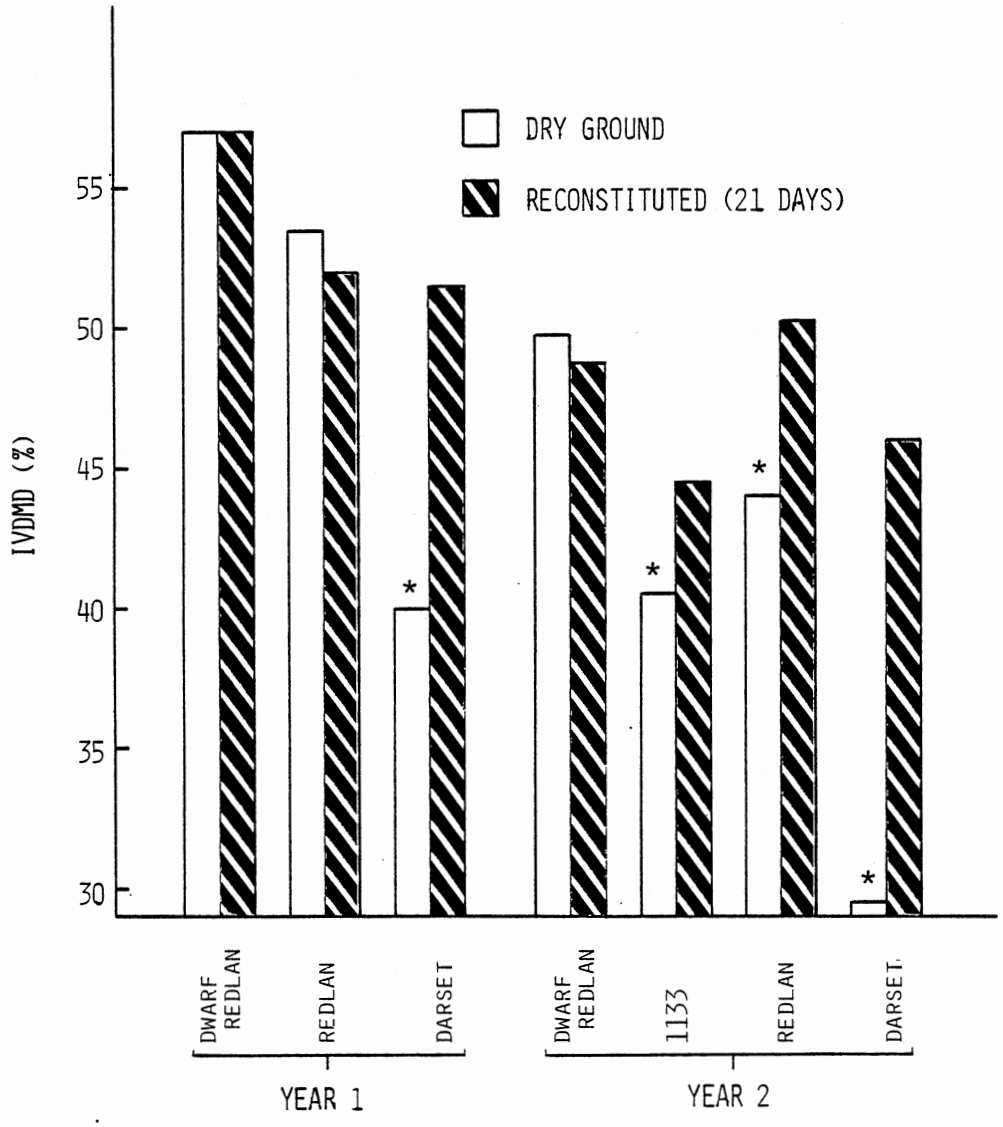


Figure 11. IVDMD of dry, ground and reconstituted (21 days) sorghum grain varieties. (* Significant reconstitution response.)

because tannins interact with proteins, varieties with high tannin content may also have the greatest potential for improvement.

Reconstitution appeared to increase IVDMD fairly rapidly in the early stages of reconstitution (Figure 12). IVDMD increased markedly on the first day for the Darset in year 1 and for all varieties in year 2. The Darset and 1133 continued to increase through the second day in year 2. Beyond day 2, however, few consistent changes in IVDMD were observed. Consequently, much of the reconstitution response had occurred within the first 2 or 3 days of incubation. Much of the response in growth rate and feed efficiency to reconstitution of sorghum may occur within 10 days of ensiling (Pantin et al., 1969; Wagner and Schneider, 1970).

Increased IVDMD probably reflects changes in the chemical or structural organization of the sorghum kernel. Total crude protein (N X 6.25) changed very little during reconstitution (Figure 13). Although highly variable, soluble (NaCl) protein tended to increase for the Redlan in both years along with the Darset in year 2 (Figure 14). A depression in soluble protein was observed for the Dwarf Redlan and Redlan varieties in both years starting as early as day 1 and continuing, in some cases, through day 16. The reason for this depression is unclear although microbial assimilation of protein solubilized by germination may be responsible for the initial depression. Subsequent increases in soluble protein levels may be due to continued protease activity in the kernel, even after fermentation has stopped (Prigge et al., 1976). Pepsin insoluble nitrogen decreased rapidly for all three varieties in year 1 (Figure 14). In year 2, PIN decreased, although more slowly, for the bird resistant sorghums (Darset and 1133).

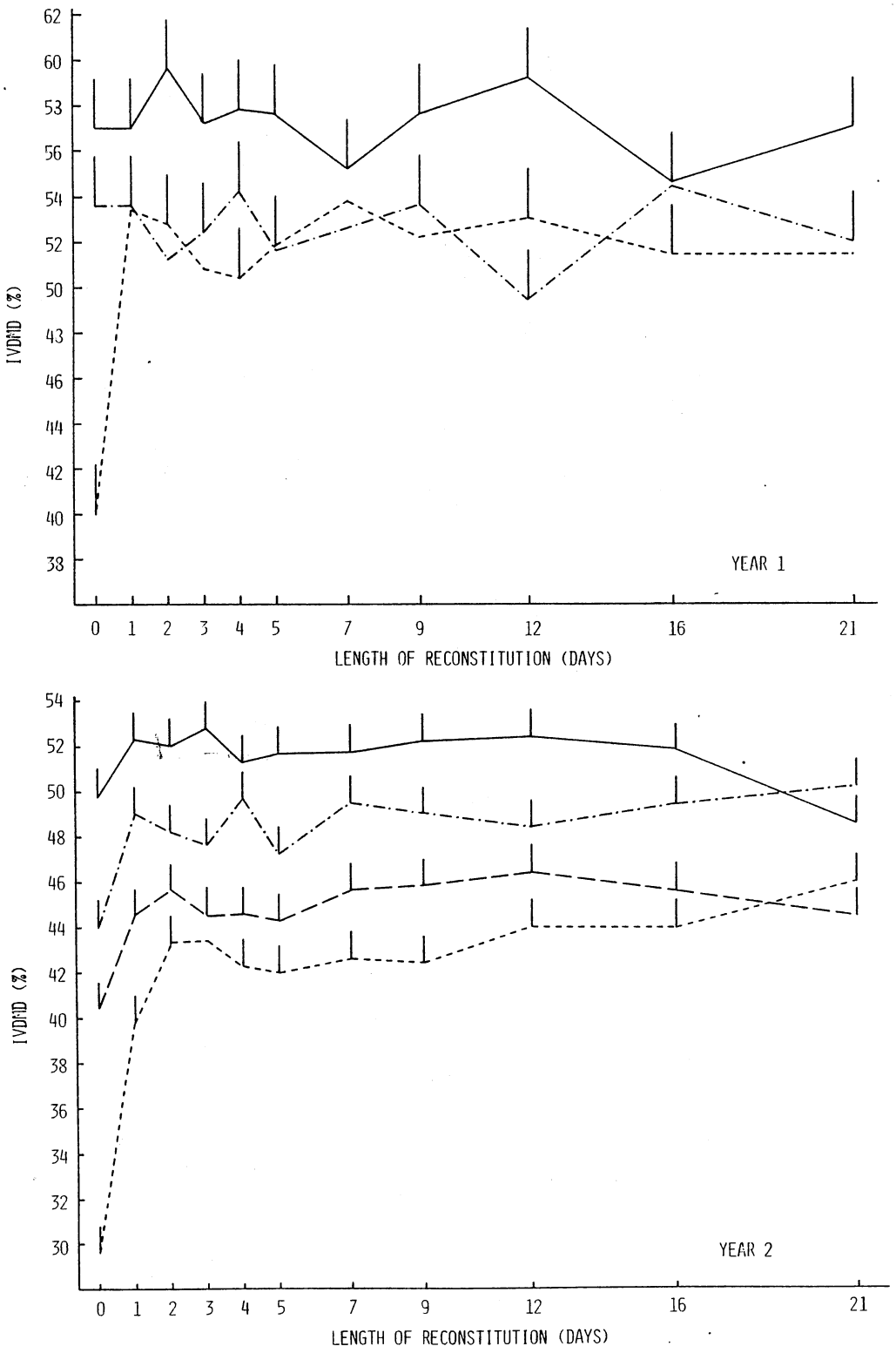


Figure 12. Changes in IVDMD associated with length of reconstitution (——— Dwarf Redlan, — — 1133, —·—· Redlan, ----- Darset).

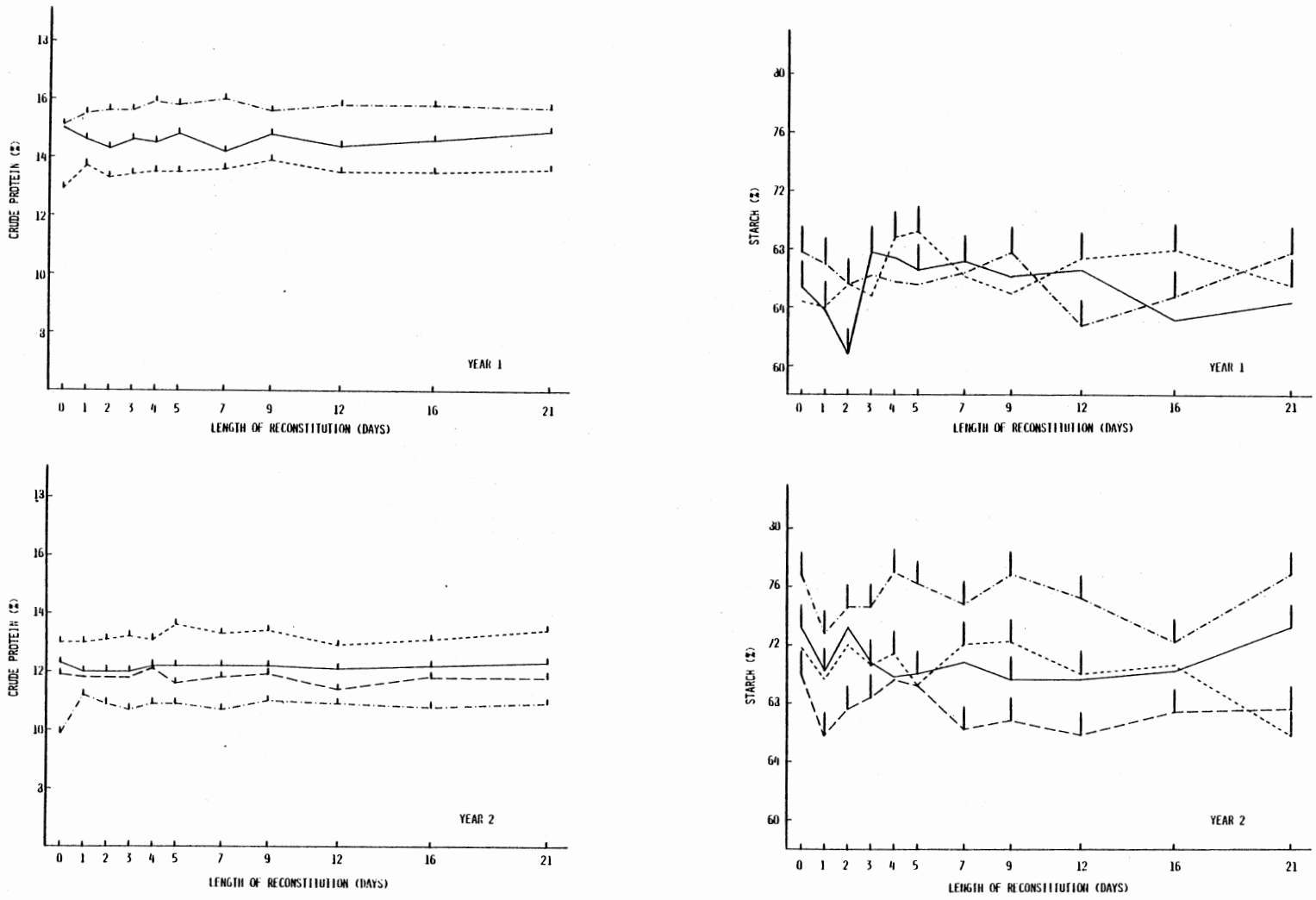


Figure 13. Protein and starch content (% of DM) of sorghum grain varieties during reconstitution (———Dwarf Redlan, — — 1133, —·—·Redlan, - - - -Darset).

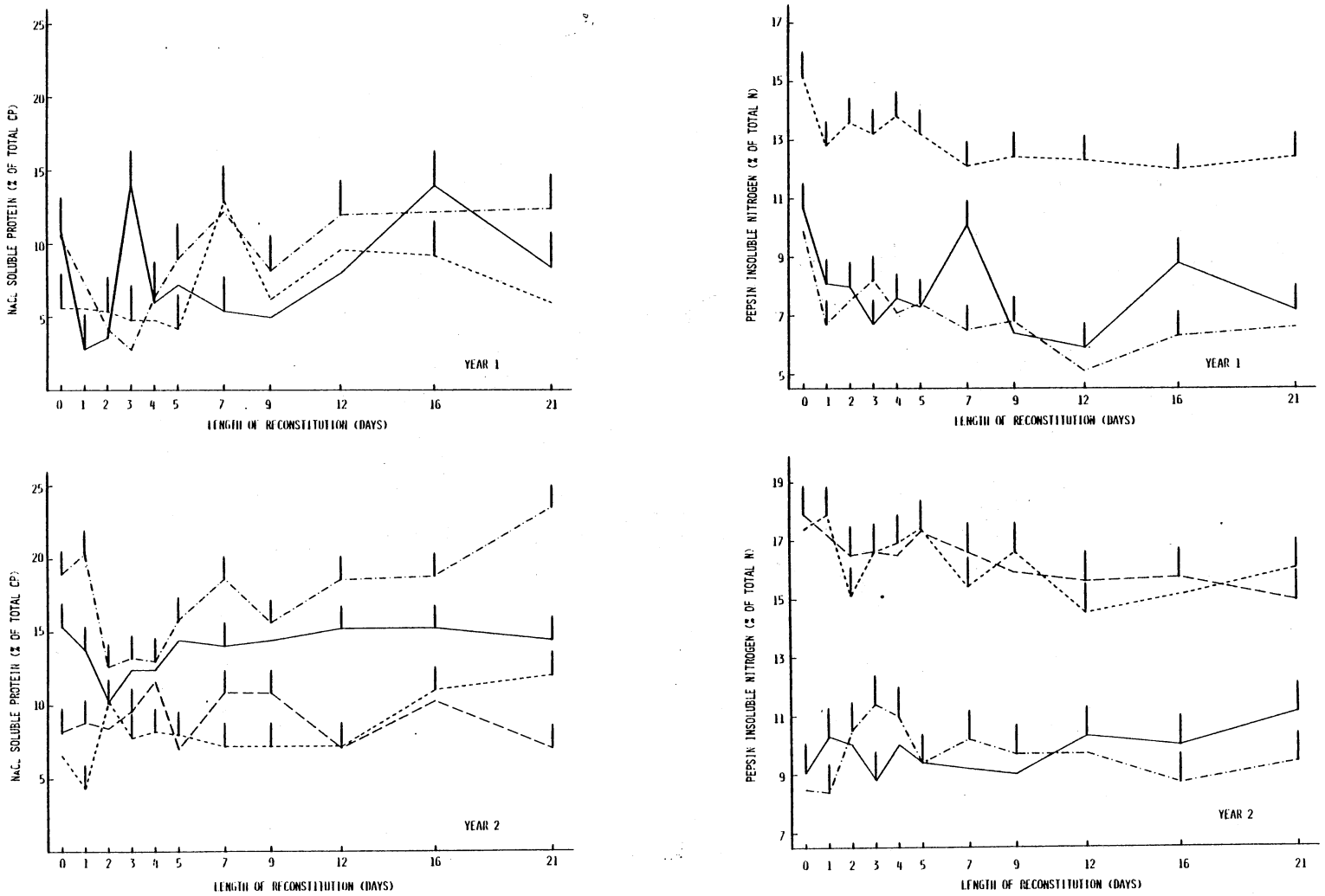


Figure 14. Salt (NaCl) soluble and pepsin insoluble protein content (% of CP) of reconstituted sorghum grain varieties (———Dwarf Redlan, — — —1133, —·—·—Redlan, ····Darset).

Reconstitution increased the PIN content of the Dwarf Redlan and Redlan varieties in year 2. The major changes occurring in the sorghum kernel during reconstitution appear to be related to the disruption of the protein matrix (Sullins et al., 1972). Reconstitution increases ruminal digestibility of sorghum protein (Potter et al., 1971). Our studies suggest that increased protein digestibility, as evidenced by decreased PIN content, is not simply the result of increased soluble protein content. Other mechanisms such as weakening of the protein matrix through disrupted protein-protein or protein-starch interactions may increase protein and starch digestibility with little effect on protein solubility.

Starch content appeared to change very little as reconstitution progressed (Figure 13). In corn, soluble carbohydrates (glucose) did not change during the first three days of germination (Ingle et al., 1964). McNeill et al. (1975) reported little change in enzymatic starch digestibility of reconstituted grain suggesting that the integrity of the starch granule remains intact. These observations further support the theory that reconstitutional changes are protein related.

Perhaps the most dramatic reconstitution effect noted in these studies is the change in tannin content of bird resistant sorghums (Figure 15). Tannin content decreased rapidly the first day for the Darset and 1133 varieties in both years. Water imbibition and storage for as little as two days can decrease the tannin content of bird resistant sorghums by as much as 60% (Chavan et al., 1979; Reichert et al., 1980). Germination also decreases tannin content very rapidly (Reichert et al., 1980). Tannin inactivation would be a logical process early in germination to allow mobilization of endosperm protein for

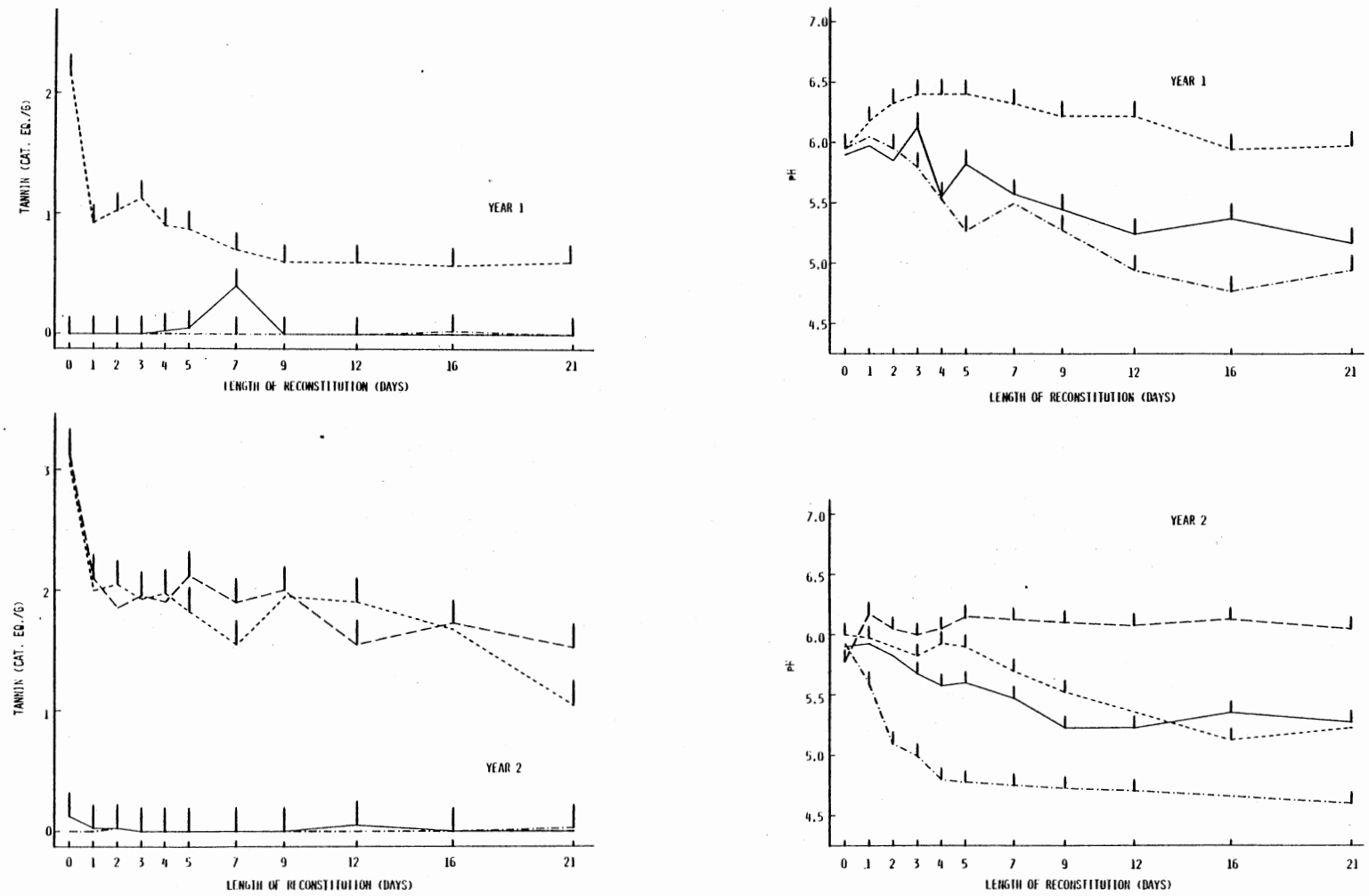


Figure 15. Changes in tannin content (cat. eq./g) and pH during reconstitution (——— Dwarf Redlan, — — 1133, —·—·Redlan, - - - - Darset).

seedling growth to proceed. Ensiling also can decrease tannin concentrations which may explain the gradual decreases in tannin content during the later stages of reconstitution (Cummins, 1971).

Hydrogen ion concentrations (pH) decreased quickly for the Redlan and Dwarf Redlan varieties in both years suggesting rapid microbial fermentation (Figure 15). Changes in pH for the Darset were much slower with little change noted before day 5 in either year. The pH of the 1133 remained largely unaffected by reconstitution. Perhaps some varieties (i.e. Redlan, Dwarf Redlan) are fermented more rapidly and more completely than others (Darset and 1133). Tannins under the pericarp of bird resistant sorghums may render the kernel more impervious to microbial attack. Because all reconstituted sorghums emitted a strong fermented odor, it is more likely that varietal differences in pH are due to differences in fermentation patterns rather than differences in extent of fermentation. For example, the characteristics of the bird resistant sorghums may have supported an alcohol fermentation while the nonbird resistants may have favored a more typical lactic acid fermentation. If this suggestion is true, a nonacidic fermentation may be most beneficial based on the IVDMD response of the Darset.

These studies reinforce the premise that the response to reconstitution differs with variety of sorghum grain. Varieties with low IVDMD when dry ground (Darset) respond much more dramatically than varieties with high initial IVDMD (Dwarf Redlan). Consequently, intensive processing of sorghum grain (steam flaking, reconstitution) be neither necessary nor economical for varieties with a high IVDMD. Furthermore, chemical characteristics of each sorghum variety will determine its response to processing. In this study, the variety with the most PIN,

most tannin and least soluble protein (Darset) responded most favorably to reconstitution.

Reconstitution effectively reduced the tannin content of bird resistant sorghums. In both years, reconstitution decreased the tannin content of the Darset and 1133 sorghums by about one catechin equivalent/g. Germination appears to decrease tannin levels by polymerization of low molecular weight phenols (Reichert et al., 1980). Whether reconstitution resulted in tannin polymerization or destruction is unclear. Although some tannin remained after reconstitution, it had little effect on IVDMD.

Much of the change in chemical composition and IVDMD that occurred as reconstitution progressed was observed in the first two to four days. This suggests that a short-term incubation period, five days, for example, may improve feeding value considerably. Many large feedlots currently discount reconstitution as a processing technique since a 21-day storage period would require a massive capital outlay for grain inventory and anaerobic storage facilities. A five day period, however, could quadruple the output of a reconstitution unit and greatly enhance the feasibility of reconstitution for large-scale feedlot operations.

CHAPTER VI

THE EFFECT OF VARIETY AND RECONSTITUTION ON THE SITE AND EXTENT OF STARCH AND PROTEIN DIGESTION OF SORGHUM GRAIN IN STEERS

Summary

Hetero-yellow (HY), red (RED) and brown (BR, high tannin) sorghum were fed either dry rolled or reconstituted (RED and BR only) to evaluate the effect of variety and reconstitution on the site and extent of starch and protein digestion in steers. Processed grains were incorporated into 88% sorghum (DM basis) diets fed in a 5 X 5 latin square. Differences between sorghum varieties were illustrated by decreased total tract starch digestibility for the dry rolled RED sorghum (86.9%) compared to the HY (91.4%) and BR (90.8%). Nitrogen digestibility was lowest for the dry rolled BR sorghum (53.1%). Ruminal fermentation of organic matter, starch and protein for the dry rolled RED tended to be lower than either the dry rolled HY or BR sorghum. Tannins in the BR sorghums were extensively (95.2%) degraded in the rumen which may have enhanced fermentation. Digestion of organic matter and starch in the small intestine was very low for dry rolled sorghums. Digestibility of nonammonia nitrogen at the ileum was greatest ($P < .06$) for the dry rolled HY compared to the dry rolled RED and BR. Reconstitution increased ($P < .05$) total tract starch digestion of the RED and tended to increase starch digestion in

BR as well. Total tract nitrogen digestibility of the RED sorghum was increased ($P < .05$) with reconstitution. The reconstitution response of the RED sorghum was due primarily to increased ($P < .05$) fermentability of organic matter and starch in the rumen. In contrast, the BR response was due primarily to enhanced digestion and absorption of starch in the small intestine. In both cases, most (97.3%) of the digestible starch of the reconstituted sorghums had disappeared when the digesta reached the terminal ileum. Substantial starch fermentation in the large intestine (as much as 15% of digestible starch for the dry rolled RED) compensated for incomplete fermentation and digestion in the rumen and small intestine. Reconstitution also increased ($P < .05$) total N (nitrogen) flow to the duodenum. The increase ($P < .05$) in flow of microbial N accounted for most of this change. Site and extent of digestion can differ substantially with different varieties of sorghum grain. Increased starch digestion associated with reconstitution may occur either in the rumen or small intestine depending on variety.

Introduction

Decreasing ground water supplies and increasing cost of irrigation may increase the use of drought tolerant crops such as sorghum grain in the Great Plains. Many livestock producers discriminate against sorghum grain in high energy finishing rations because of the highly variable quality of the grain and the lower feeding value relative to corn (Morrison, 1959). Different varieties of sorghum grain produce wide differences in growth rates and feed efficiencies in cattle trials (McCollough et al., 1972; Maxson et al., 1973). These differences in growth rate may be partially explained by differences in digestibility

(Nishimuta et al., 1969; McCollough and Brent, 1972).

Differences in digestibility could occur in the rumen or in the intestine. Steam flaked sorghum is fermented more completely than dry rolled sorghum in the rumen (Hinman and Johnson, 1974a). Certain endosperm types of sorghum also may be more highly fermentable than others (Samford et al., 1971). Processing methods or varieties that increase intestinal digestion and absorption may enhance feed efficiency considerably (Black, 1971).

Reconstitution is an inexpensive and energy efficient grain processing technique which may increase rumen fermentation (McNeill et al., 1971; Hale and Prouty, 1980). Different varieties of sorghum grain, however, may not respond the same to processing (Saba et al., 1972). Variety specific responses to reconstitution have been suggested in vitro (Hibberd, 1979). But the extent to which different varieties of sorghum grain differ in site and extent of digestion is unknown. Furthermore, various sorghum grain varieties respond differently to reconstitution and the effect of reconstitution on site and extent of digestion is unclear. The objectives of this study were to evaluate the effects of variety of sorghum grain and reconstitution on:

(1) chemical composition and in vitro digestibility,

(2) the extent of starch digestion (fermentation) in the rumen, small and large intestine of beef cattle, and,

(3) the extent of sorghum protein bypass to the small intestine of beef cattle.

Materials and Methods

Three varieties of sorghum grain were evaluated in two phases.

First, laboratory studies critically evaluated chemical composition and *in vitro* digestibility. Secondly, cannulated steers were used to evaluate site and extent of digestion. Hetero-yellow (HY), red (RED) and brown (BR) sorghums (Table XVI) obtained from three different locations in Oklahoma were fed either dry rolled or reconstituted (RED and BR only). Grain was reconstituted by raising the moisture level to about 30% followed by anaerobic storage in polyurethane bags (35 kg grain/bag) for 21 days. After reconstitution, both dry and reconstituted grains were rolled through a 31 X 46 cm rollermill. Each grain was incorporated at the same level of dry matter into an 88% grain ration (Table XVII). Complete rations were stored at -5 C until fed. Sorghum grain constituted a large portion (88%) of the ration so that most of the nonammonia nonmicrobial nitrogen reaching the duodenum would be of grain origin and thus provide a clearer estimate of ruminal bypass. Urea (1.2% of DM) was included to insure that levels of ammonia in the rumen were adequate. Chromic oxide (.20% of DM) was added as an indigestible marker.

Laboratory Phase

Reconstituted grain and feed samples were lyophilized prior to analysis. Samples were ground through a Udy mill (1 mm screen) for compositional analysis. Particle size distribution (Ensor et al., 1970) was determined on lyophilized, unground feed samples (Table XVIII). Starch content was measured as α-linked glucose polymers (MacRae and Armstrong, 1968). Crude protein (N X 6.25) and ash were analyzed by AOAC (1975) procedures and acid detergent fiber by the Van Soest technique (1962). Protein composition was determined on the basis of

TABLE XVI. DESCRIPTIVE CHARACTERISTICS OF SORGHUM GRAINS

Sorghum	Abbreviation	Seed coat color	Endosperm color	Testa layer[a]
Hetero-yellow	H-Y	yellow	hetero-yellow	absent
Red	RED	red	white	absent
Brown	BR	brown	white	present

[a]Presence of testa layer indicative of high tannin content and bird resistance.

TABLE XVII. INGREDIENT COMPOSITION OF EXPERIMENTAL DIETS (DRY MATTER BASIS)

Ingredient	IFN #	%
Sorghum grain	4-04-383	88.0
Cottonseed hulls	1-01-599	8.0
Supplement		
Urea	5-05-070	1.20
Dicalcium phosphate	6-01-080	0.44
Calcium carbonate	6-01-069	0.93
Potassium chloride	6-03-756	0.57
Sodium sulfate	6-04-292	0.36
Sodium chloride	6-04-152	0.25
Chromic oxide		0.20
Vitamin A	7-05-143	2200 IU/kg

TABLE XVIII. PARTICLE SIZE DISTRIBUTION OF LYOPHILIZED FEED SAMPLES

Average geometric diameter (μm)	Dry-rolled			Reconstituted	
	Het-yel	Red	Brown	Red	Brown
	%				
5657	1.00	1.83	2.62	3.44	4.36
2828	16.26	12.40	14.89	45.06	26.20
1414	57.90	47.45	52.78	25.58	45.46
707	15.24	25.42	19.10	13.02	15.04
354	4.61	5.70	5.20	10.44	8.22
177	2.80	4.08	2.78	2.14	0.48
88	2.19	3.12	2.62	0.31	0.25
GMD, μm[abcdefg]	1202.5	1032.0	1163.4	1520.4	1423.7
Geometric standard deviation, μm	2.1	2.2	2.2	2.2	2.2

[a]Variety by processing interaction ($P < .05$).

[b]HY vs. all others ($P < .05$).

[c]Dry rolled RED vs. reconstituted RED ($P < .05$).

[d]Dry rolled BR vs. reconstituted BR ($P < .05$).

[e]Dry rolled RED vs. dry rolled BR ($P < .05$).

[f]Reconstituted RED vs. reconstituted BR ($P < .05$).

[g]GMD = Geometric mean diameter.

differential solubility in the Landry-Moureaux Fractionation Sequence D (Landry and Moureaux, 1970). Soluble protein was measured with a 6-h incubation of a .5 g sample in 50 ml of .15 N NaCl at 39 C (Waldo and Goering, 1979). Pepsin indigestibility was determined by a 20-h incubation (39 C) of a 1 g sample with 100 ml of .1 N HCl and 1 g pepsin (Goering and Van Soest, 1970). Tannin content was measured as catechin equivalents using a vanillin-HCl procedure (Burns, 1971) as modified by Price et al. (1978).

In vitro dry matter disappearance (IVDMD) was estimated for grain and feed samples ground through a 20-mesh (2 mm) screen in a laboratory Wiley mill. Dry ice was used to facilitate grinding of the wet samples. In vitro dry matter disappearance was calculated by weight difference after an 18-h incubation (39 C) with buffered rumen fluid (15 ml rumen fluid: 15 ml buffer; McDougall, 1948) obtained from an Angus steer fed an 80% corn diet (Hibberd, 1979). In vitro gas production was determined by either a 6- or 12-h incubation (39 C) with .25 g commercial baker's yeast and 10 ml of a 1% (w/v) amyloglucosidase (E.C. No. 3.2.1.3) solution (Hibberd, 1979).

Steer Phase

Five crossbred steers (340 kg) were fitted with permanent ruminal, duodenal (3 cm distal to pylorus) and ileal (20 cm cranial to the ileocecal junction) T-type cannulae. Steers were fed 5 different rations (Table XVII) at 2% (DM) of body weight in a 5 X 5 latin square design. Experimental periods were 10 days in length consisting of 7 days of adaptation and 3 days of sampling. During sampling, steers were fed at 0800 and 2000 hours and sampled at 1000, 1400 and 1800 hours. Digesta

samples (500 ml duodenal and 250 ml ileal fluid) were composited across time and stored at 5 C until the end of the period. Ruminal fluid (1000 ml) was collected at 1000, 1400 and 1800 hours on day 3 of sampling only. After pH determination, rumen samples were acidified by addition of 3.3 ml of 36 N H_2SO_4 per liter of ruminal fluid.

Composited digesta was subsampled and dried at 55 C in a forced air oven. Dried samples were ground through a 1 mm screen in a Udy mill prior to analysis. In addition to the procedures described in the previous section, digesta was also analyzed for: (1) ammonia-N by MgO distillation (AOAC, 1975); (2) chromic oxide (Fenton and Fenton, 1979) and (3) nucleic acid-N (Zinn and Owens, 1982a). Appearance and digestibility of various feed components in different segments of the digestive tract were calculated by chromic oxide ratios. Microbial N was calculated as nucleic acid N/.15 (Ellis and Pfander, 1965; McAllan and Smith, 1972). Feed N (plus endogenous) reaching the duodenum was calculated as total duodenal N minus NH_3-N and microbial N. Organic matter reaching the duodenum was corrected for microbial organic matter on the assumption that ruminal bacteria contained 50% crude protein (N X 6.25) and 20% ash (Smith, 1975).

Statistical Analysis

Data from the *in vitro* analyses of the laboratory phase can be described by:

$$Y_{ij} = \mu + D_i + R_j + E_{ij}$$

where Y_{ij} is the parameter of interest, D is diet and R is run. The components μ, D_i and R_j were treated as fixed effects of all records of diet i and run j. Random error effect, E_{ij}, was specific to each

observation. Analysis of parameters other than IVDMD omitted the run term.

Data from the steer phase (5 X 5 latin square) can be described by:

$$Y_{ijk} = \mu + A_i + P_j + D_k + E_{ijk}$$

where Y_{ijk} is the variable of interest and A is animal, P is period and D is diet. The components μ, A_i, P_j and D_k were treated as fixed effects of all records of animal i, period j and diet d. Random error effect, E_{ijk}, was specific to each observation.

Estimated differences between treatment (diet) means were obtained by method of least squares. Comparisons between treatment means were based on orthogonal contrasts illustrated in Table XIX. When the variety X processing interaction was significant, differences between simple effects were detected by t-test (Federer, 1967).

Results and Discussion

Starch content (%) was greatest for the RED (70.8%) followed by the HY (68.4%) and BR (65.0%) grains (Table XX). Elevated tannin levels were observed with the BR grain as is often the case with bird resistant types (Bullard et al., 1980). Reconstitution decreased tannin content of the grain by 8% and the feed by 30%. Reduction of tannin concentration has been documented (Reichert et al., 1980). Total protein (N X 6.25) was similar for the HY (14.08%) and BR (13.35%) and greater ($P < .05$) than the RED (10.37%). Soluble (NaCl) protein levels of the dry rolled grains were similar (5.32 to 6.76%). Reconstitution decreased ($P < .05$) the soluble protein content of the BR grain, but not the RED. Pepsin insoluble nitrogen (PIN) was similar for the dry rolled grains (14.0 to 17.4%) but increased with reconstitution for the BR

TABLE XIX. ORTHOGONAL CONTRASTS BETWEEN TREATMENT MEANS

	Dry rolled			Reconstituted	
Contrast	Het-yel	Red	Brown	Red	Brown
a	0	+1	+1	-1	-1
b	0	+1	-1	+1	-1
c	0	+1	-1	-1	+1
d	+4	-1	-1	-1	-1

TABLE XX. CHEMICAL CHARACTERISTICS OF PROCESSED SORGHUM GRAINS AND COMPLETE MIXED FEEDS (DRY MATTER BASIS)

	Dry-rolled			Reconstituted		
	Het-yel	Red	Brown	Red	Brown	SE
Grain						
Crude protein (%)[bd]	14.08	10.37	13.35	10.76	13.22	.28
Starch (%)[b]	68.44	70.79	64.97	72.92	65.70	.66
Ash (%)[cdefgh]	1.70	1.60	1.95	1.76	2.22	.01
Tannin (cat.eq./g)[bd]	.06	.03	1.31	.04	1.21	.06
NaCl soluble protein (%)[cfh]	5.32	6.76	6.34	7.52	4.60	.46
Pepsin insoluble nitrogen (%)[ch]	17.4	14.0	16.4	10.4	20.1	1.1
Landry-Moureaux (%)						
Fraction I[cdfgh]	11.98	18.52	15.85	19.61	13.38	.68
Fraction II[cegh]	7.79	14.93	3.75	12.01	5.40	.53
Fraction III[bd]	23.48	21.22	16.28	22.44	17.48	1.17
Fraction IV[cdfgh]	6.75	7.50	13.64	8.34	11.26	.42
Fraction V[cdfgh]	45.78	30.01	51.91	28.49	43.04	.79
Feed						
Crude protein (%)[bd]	16.88	13.31	15.47	13.39	15.31	.14
Starch (%)[ab]	66.65	69.32	62.44	66.94	57.93	1.46
Ash (%)[cfgh]	4.08	4.05	4.26	3.95	4.53	.06
Acid detergent fiber (%)[ab]	7.48	3.72	6.00	8.40	10.46	.45
Tannin (cat.eq./g)[cdfgh]	.03	.04	1.22	.04	.86	.02
NaCl soluble protein (%)[cdefgh]	13.27	16.80	12.50	17.86	15.14	.23
Pepsin insoluble nitrogen (%)[bd]	6.26	6.52	13.43	5.54	12.95	.55

[a] Dry rolled (RED and BR only) vs. reconstituted ($P < .05$).
[b] RED vs. BR ($P < .05$).
[c] Variety X processing interaction ($P < .05$).
[d] HY vs. all others ($P < .05$).
[e] Dry rolled RED vs. reconstituted RED ($P < .05$).
[f] Dry rolled BR vs. reconstituted BR ($P < .05$).
[g] Dry rolled RED vs. dry rolled BR ($P < .05$).
[h] Reconstituted RED vs. reconstituted BR ($P < .05$).

grain. The RED grain contained more ($P < .05$) albumin and globulin (Fraction I) and kafirin (Fraction II and III) protein than the BR grain both before and after reconstitution. Increased ($P < .05$) glutelin (Fraction IV and V) is typical of bird resistant sorghum grain (Jambunathan and Mertz, 1973; Chibber et al., 1978). Reconstitution decreased ($P < .05$) the glutelin content of the BR grain although less total protein was solubilized.

The HY and RED sorghums were similar in IVDMD and superior (RED vs. BR, $P < .05$) to the BR in both the grain and feed form (Table XXI). A lower IVDMD is often observed with bird resistant sorghums (Saba et al., 1972). Starch availability (IVGP) of the RED grain was greater ($P < .05$) than for the BR grain. In the complete feed, however, starch availability was greatest for the HY followed by the RED and finally the BR feed. Reconstitution increased ($P < .05$) the IVDMD of the RED and BR sorghums in both the grain and feed form. Reconstitution also increased the starch availability of the RED and BR grain and feeds, especially after 12 h of incubation. The BR was increased to a greater extent in the grain form while the RED increased more in the feed form. High tannin, bird resistant sorghum varieties respond more in IVDMD and IVGP to grain processing than other sorghum types (Saba et al., 1972; Hibberd, 1979).

Steer Phase

Variety effects. Total tract organic matter (DM) digestibilities of the dry rolled RED and BR sorghums were similar (Table XXII). Although not significant ($P > .05$), total tract organic matter digestibility of the dry rolled HY was greater than the dry rolled RED and BR.

TABLE XXI. IVDMD AND IVGP OF DRY ROLLED AND RECONSTITUTED SORGHUM GRAINS AND COMPLETE, MIXED FEEDS

	Dry-rolled			Reconstituted		
	Het-yel	Red	Brown	Red	Brown	SE
Grain						
IVDMD (%)[ab]	48.6	50.1	36.6	54.7	42.6	1.9
IVGP (ml gas/g DM)						
6-h[cdfg]	81.7	107.5	83.6	111.6	108.1	2.0
12-h[cdefgh]	96.6	121.2	97.6	132.4	121.5	2.3
Feed						
IVDMD (%)[ab]	49.5	52.7	39.2	54.4	44.3	1.7
IVGP (ml gas/g DM)						
6-h[cdefgh]	91.0	86.2	80.4	122.2	92.7	1.0
12-h[cdefgh]	103.5	100.4	91.5	130.2	103.2	1.1

[a]Dry rolled (RED and BR only) vs. reconstituted ($P < .05$).
[b]RED vs. BR ($P < .05$).
[c]Variety X processing interaction ($P < .05$).
[d]HY vs. all others ($P < .05$).
[e]Dry rolled RED vs. reconstituted RED ($P < .05$).
[f]Dry rolled BR vs. reconstituted BR ($P < .05$).
[g]Dry rolled RED vs. dry rolled BR ($P < .05$).
[h]Reconstituted RED vs. reconstituted BR ($P < .05$).

TABLE XXII. EFFECT OF VARIETY AND PROCESSING ON TOTAL TRACT DIGESTION

	Dry rolled			Reconstituted		
	Het-yel	Red	Brown	Red	Brown	SE
Feces (g/day)						
Fecal output (kg/day)[ceh]	7.0	8.7	9.3	5.6	8.8	.6
Fecal pH[cdefg]	5.49	5.52	5.73	6.02	5.95	.06
Organic matter[ab]	1643	2118	2172	1288	1907	136
Starch[ce]	408	634	422	75	216	77
Tannin (cat.eq./day)[bd]	2.5	2.8	11.7	4.0	10.3	.8
Acid detergent fiber[bd]	423	515	783	512	734	22
Total N[ab]	67.0	66.3	83.9	48.4	77.7	3.5
NH_3-N[bd]	1.0	0.9	1.6	1.1	1.7	.1
Nonammonia N[ab]	66.0	65.4	82.4	47.3	76.0	3.5
RNA-N[ceh]	2.2	3.0	2.6	1.4	2.9	.3
Total tract digestibility (%)						
Organic matter[ceh]	75.8	68.4	68.7	81.2	72.1	1.9
Starch[ce]	91.4	86.9	90.8	98.4	94.8	1.5
Total feed N based on:						
Total Fecal N[cdeh]	64.5	55.3	53.1	68.2	55.7	2.1
Fecal nonammonia N[cdeh]	65.0	55.9	54.0	69.0	56.6	2.0
Digestibility in cecum and large intestine (%)						
Organic matter[d]	33.2	31.6	15.7	16.8	17.8	4.6
Starch	57.3	48.6	42.1	40.8	18.0	15.8
Total N	2.6	2.1	-3.1	-.4	-1.2	3.7
Nonammonia N	.7	1.6	-3.6	.2	-1.5	3.9

[a] Dry rolled (RED and BR only) vs. reconstituted ($P < .05$).
[b] RED vs. BR ($P < .05$).
[c] Variety X processing interaction ($P < .05$).
[d] HY vs. all others ($P < .05$).
[e] Dry rolled RED vs. reconstituted RED ($P < .05$).
[f] Dry rolled BR vs. reconstituted BR ($P < .05$).
[g] Dry rolled RED vs. dry rolled BR ($P < .05$).
[h] Reconstituted RED vs. reconstituted BR ($P < .05$).

Starch digestibility was poorest for the RED sorghum. Total tract nitrogen digestibility was greater ($P<.05$) for the HY than the RED or BR. Depressed protein digestibility is often noted with bird resistant sorghum rations although other components may or may not be affected (McCollough and Brent, 1972; Maxson et al., 1973).

Ruminal fermentation of organic matter, starch and nonammonia nonmicrobial N was lower for the dry rolled RED sorghum than the dry rolled HY and BR (Table XXIII). This result is somewhat surprising in light of IVDMD results. Grain samples for IVDMD were finely ground, however, and inoculum was obtained from a steer not adapted to high tannin diets. The high extent of digestion of OM, starch and protein of the BR sorghum may be attributed to the fact that 95.2% of its tannin disappeared in the rumen. Whether the tannin was degraded or merely metabolized into products undetectable by the vanillin-HCl assay is unknown. Nevertheless the deleterious effects commonly expected for high tannin sorghums were not observed. Low fermentability of the RED sorghum protein is reflected by decreased ($P < .05$) rumen ammonia levels and increased ruminal escape of dietary protein relative to the dry rolled HY and BR sorghums. Microbial efficiency (g microbial protein/100 g organic matter fermented) was greater ($P < .05$) on the dry rolled RED sorghum diet than the dry rolled HY and BR. Low ruminal organic matter fermentation coupled with similar levels of microbial production enhanced the efficiency of the RED sorghum. Microbial efficiency appears to be enhanced as fermentability of the ration decreases (Bergen et al., 1982).

Trends in organic matter and starch digestibility of dry rolled sorghums through the ileum were similar to trends observed in ruminal fermentation (Table XXIV). Digestibility of nonammonia N through the

TABLE XXIII. EFFECT OF VARIETY AND PROCESSING ON RUMINAL DIGESTION

	Dry-rolled			Reconstituted		
	Het-yel	Red	Brown	Red	Brown	SE
Intake (g/day)						
Organic matter	6734	6674	6901	6833	6799	61
Starch	4679	4822	4501	4762	4126	46
Tannin (cat.eq./day)	1.9	2.6	88.1	2.7	61.7	1.4
Acid detergent fiber	525	259	432	598	745	7
Total feed N	188.3	148.2	178.4	152.4	174.5	1.6
Feed N (excluding urea)	149.0	109.2	138.0	112.6	134.6	1.3
Rumen						
NH_3-N (mg/dl)[abd]	14.83	9.06	12.12	4.74	5.63	.86
pH	5.83	5.80	5.84	5.79	5.68	.07
Leaving abomasum (g/day)						
Chyme (l/day)[abd]	60.2	63.9	69.4	68.5	74.2	1.8
Chyme pH[ceh]	2.59	2.66	2.60	2.37	2.81	.09
Total organic matter[ceh]	3633	4253	3833	3063	3827	200
Nonmicrobial organic matter[ceh]	2805	3409	2974	1994	2823	213
Starch[ceg]	1362	1923	1131	482	943	172
Tannin (cat.eq./day)[bd]	1.65	1.98	4.21	1.10	4.74	.55
Acid detergent fiber[bd]	417	498	716	577	719	38
Total N[ab]	188.4	173.2	193.3	183.3	206.9	5.3
NH_3-N[b]	11.1	8.6	11.7	9.1	12.1	.5
Microbial N[ad]	82.8	84.4	85.9	106.9	100.4	3.6
Nonammonia nonmicrobial N[b]	94.5	80.1	95.6	67.3	94.4	5.5
Rumen digestibility (%)						
Organic matter (corrected)[ceh]	58.5	48.9	57.3	70.8	58.3	3.1
Starch[cegh]	71.1	60.2	75.2	89.8	77.0	3.5
Tannin[bd]	14.4	24.8	95.2	60.6	92.2	17.4
Total feed N[i]	49.9	45.6	46.6	55.7	45.8	3.2
Feed N (excluding urea)[i]	36.7	26.3	31.0	40.0	29.8	4.2
Rumen digestibility (% of total digestibility)						
Organic matter (corrected)[ceg]	77.2	71.4	83.1	87.3	81.2	3.6
Starch[cegh]	77.8	69.1	82.7	91.1	81.2	3.2
Total feed N[i]	77.4	82.1	87.4	82.7	82.9	5.2
Rumen bypass by nonammonia nonmicrobial N (%)	63.3	73.7	69.0	60.0	70.2	4.2
Microbial efficiency g MP/100 g OMF[cefgh]	13.3	16.3	13.7	13.8	16.0	.7

[a] Dry rolled (RED and BR only) vs. reconstituted ($P < .05$).
[b] RED vs. BR ($P < .05$).
[c] Variety X processing interaction ($P < .05$).
[d] HY vs. all others ($P < .05$).
[e] Dry rolled RED vs. reconstituted RED ($P < .05$).
[f] Dry rolled BR vs. reconstituted BR ($P < .05$).
[g] Dry rolled RED vs. dry rolled BR ($P < .05$).
[h] Reconstituted RED vs. reconstituted BR ($P < .05$).
[i] Based on nonammonia microbial N reaching the duodenum.

TABLE XXIV. EFFECT OF VARIETY AND PROCESSING ON SMALL INTESTINAL DIGESTION

	Dry-rolled			Reconstituted		
	Het-yel	Red	Brown	Red	Brown	SE
Leaving ileum (g/day)						
Chyme (l/day)[cedh]	15.6	19.2	18.4	15.4	19.6	.8
Chyme pH[a]	6.40	6.30	6.50	6.94	6.83	.12
Organic matter[ceh]	2473	3086	2605	1598	2324	163
Starch[cedfh]	951	1255	727	201	317	102
Tannin (cat.eq./day)[abd]	4.0	6.1	12.5	1.8	9.2	1.0
Acid detergent fiber[bd]	498	582	792	572	861	28
Total N[ab]	69.2	67.7	81.7	49.0	76.9	4.2
NH_3-N[bd]	2.2	1.3	1.8	.8	1.9	.2
Nonammonia N[ab]	67.0	66.4	79.8	48.1	75.0	4.2
Total digestibility through ileum (%)						
Organic matter[cegh]	63.5	54.0	62.6	76.8	65.9	2.2
Starch[cdefg]	80.0	74.1	84.1	95.9	92.4	2.0
Total feed N based on:						
Total ileal N[ceh]	63.4	54.4	54.4	67.9	56.0	2.4
Ileal Nonammonia N[ceh]	64.6	55.3	55.5	68.5	57.1	2.4
Ileal digestibility (% of total digestion)						
Organic matter[ceg]	84.0	79.2	90.9	94.4	91.4	2.4
Starch[ad]	87.5	85.5	92.6	97.3	97.3	1.8
Total feed N based on:						
Total ileal N	98.4	98.6	102.4	99.2	100.7	2.3
Ileal Nonammonia N	99.5	99.1	102.7	99.0	100.9	2.3
Digestibility in small intestine (%)						
Organic matter[ceh]	31.9	27.3	32.5	47.8	38.4	2.6
Starch[ad]	28.6	33.4	34.8	70.9	67.5	3.3
Total N[ab]	63.4	61.1	58.0	73.1	62.5	1.8
Nonammonia N[ab]	62.4	59.8	56.3	72.2	61.2	2.0
RNA-N	86.5	85.7	83.4	90.8	86.6	2.2

[a]Dry rolled (RED and BR only) vs. reconstituted ($P < .05$).
[b]RED vs. BR ($P < .05$).
[c]Variety X processing interaction ($P < .05$).
[d]HY vs. all others ($P < .05$).
[e]Dry rolled RED vs. reconstituted RED ($P < .05$).
[f]Dry rolled BR vs. reconstituted BR ($P < .05$).
[g]Dry rolled RED vs. dry rolled BR ($P < .05$).
[h]Reconstituted RED vs. reconstituted BR ($P < .05$).

ileum for the dry rolled HY, however, was substantially greater than the dry rolled RED or BR compared to differences in rumen digestibility.

Reconstitution effects. Reconstitution increased ($P < .05$) the total tract digestibility of OM (68.4 to 81.2%), starch (86.9 to 98.4%) and N (55.3 to 68.2%) for the RED sorghum (Table XXII). Although not significant, reconstitution increased OM, starch and N digestibility of the BR sorghum as well. Increased OM, starch and protein digestibility are typical for reconstituted sorghum rations (Buchanan-Smith et al., 1968; McNeill et al., 1971; Potter et al., 1971).

Most of the increase in total starch digestion of the reconstituted RED sorghum was due to increased ruminal fermentation (Table XXIII). Almost all (91.1%) of the digestible starch in the reconstituted RED sorghum was fermented in the rumen compared to 69.1% for the dry rolled RED. McNeill et al. (1971) also observed a similar increase in ruminal starch fermentation for reconstituted sorghum. Ruminal starch fermentation of the BR sorghum, however, was not appreciably altered by reconstitution. In this study, reconstitution did not alter the tannin content of the BR as much as has been observed with other bird resistant sorghums (Reichert et al., 1980; see also Chapter V of this dissertation). Perhaps tannins limited the action of reconstitution of the BR sorghum in this study.

Reconstitution increased ($P < .05$) the total quantity of N reaching the duodenum (Table XXIII). Most of this increase can be attributed to increased ($P < .05$) microbial N production. Decreased ($P < .05$) rumen ammonia levels for the reconstituted sorghums are probably indicative of enhanced microbial assimilation. Potter et al. (1971) found that reconstitution lowered the amount of N reaching the abomasum. Lack of

fermentable N in the diet could have limited microbial growth in the rumen in their study. In contrast, a ground high moisture corn diet had increased total and microbial N flow to the abomasum when compared to a dry rolled corn diet (Prigge et al., 1978). In their study, increased microbial N production was associated with increased chyme flow to the abomasum. Reconstitution increased ($P < .05$) chyme flow in our study as well. This may reflect an increased dilution rate. Increased dilution rate usually enhances microbial growth and efficiency (Owens and Isaacson, 1977). Microbial efficiency was increased by reconstitution of BR where chyme flow was greatest.

Starch digestion of the reconstituted sorghums was almost complete (97.3% of total digestion) at the ileum (Table XXIV). The bulk of this increase was noted in the rumen for the RED but in the small intestine for the BR. Consequently, feeding the reconstituted BR used in this study should theoretically produce greater efficiency of feed use (kg feed/kg body weight gain) than with the reconstituted RED sorghum (Black, 1971). Reconstitution appears to increase sorghum utilization via solubilization of the protein matrix rendering the starch more accessible to digestive action (Sullins et al., 1971). Our study suggests that reconstitution increased starch accessibility, but the site - in the rumen or in the small intestine - depended on the variety of sorghum used.

Because of incomplete digestion in the small intestine, fermentation of starch in the large intestine was relatively more important for the dry rolled than reconstituted sorghums. As much as 621 g of starch were fermented in the large intestine of steers fed the dry rolled RED sorghum compared to 126 g for the reconstituted RED

(Table XXII). In this study, the large intestine was able to compensate for inadequate fermentation and digestion in the rumen and small intestine so that starch digestion of the dry rolled and reconstituted sorghums was more similar in the feces than in ileal samples. Utilization of carbohydrates and absorption of endproducts in the large intestine appears to be substantially less efficient than in the rumen or small intestine (Ørskov et al., 1970). Consequently, processing methods, such as reconstitution, that increase utilization of nutrients before the ileum should result in the greatest efficiency of feed use (Waldo, 1973).

These studies illustrate the potential of sorghum variety and reconstitution for altering the site and extent of starch and protein digestion in beef cattle. Ruminal starch fermentation ranged from 60.2 to 75.2% for the dry sorghum grains tested. An even greater range might be observed with more divergent types of sorghum. Reconstitution increased total tract starch digestibility, especially for the RED sorghum. Increased ruminal starch fermentation was observed for the reconstituted RED while enhanced small intestinal digestion was observed for the reconstituted BR. In either case, starch digestion of the reconstituted sorghums was nearly complete at the ileum. These studies help to explain the variable feeding response often observed with dry rolled sorghum grain. In addition, the theory that different varieties of sorghum respond differently to reconstitution is strengthened. Future work should concentrate on specific, commonly grown, sorghum hybrids to evaluate: (1) utilization when dry rolled and (2) response to grain processing techniques such as reconstitution or steam flaking.

More complete information should help sorghum breeders and livestock producers improve the efficiency of sorghum grain utilization.

CHAPTER VII

SUMMARY

Three experiments were conducted with several widely divergent types of sorghum grain to evaluate the effects of nitrogen (N) fertilization, stage of maturity and length of reconstitution on chemical composition and IVDMD. Sorghum types used were a waxy (Dwarf Redlan), waxy bird resistant (1133), normal (Redlan) and two normal bird resistants (Darset and ROKY 78). A fourth experiment was conducted to evaluate the effect of sorghum grain type, hetero-yellow (HY), red (RED) or brown (BR, bird resistant), and reconstitution (RED and BR only) on site and extent of starch and protein digestion in beef steers.

Experiment I

Additional N fertilization (56 kg/ha applied midway through growing season) had little effect on starch or tannin content (%). When additional N increased berry size, protein content (%) changed very little, suggesting that soil N levels were inadequate for maximum yield. In contrast, when berry size was unaffected, fertilization increased glutelin and kafirin deposition (g/berry). Additional N increased IVDMD of all sorghums in year 2 when soil N levels appeared to be adequate for maximal yield. This study suggests that the protein characteristics (content and composition) of sorghum grain can be altered by the addition of extra N during the growing season. Also, when economically feasible,

extra N fertilization may enhance the feeding value of sorghum grain through an increase in digestibility.

Experiment II

Sorghum grain was harvested at weekly intervals. Physiological maturity (maximum dry matter deposition) was attained at a dry matter content between 65 and 70%. Starch (%) increased through 55 and 60% DM although starch deposition (g/berry) did not peak until about 70% DM. Starch deposition beyond 55% DM is probably a reflection of increased berry size. Protein and ash content (%) decreased through maturity although protein deposition (g/berry) peaked around 70% DM. Soluble protein decreased and pepsin insoluble nitrogen (PIN) generally increased as maturity progressed indicative of glutelin and kafirin deposition. Tannin content of the bird resistant sorghums decreased rapidly through 70% DM. As maturity progressed, IVDMD decreased, presumably due to dehydration and compaction of chemical and structural elements of the sorghum kernel. Varietal differences, especially in soluble protein and IVDMD, were negligible early in maturity (35% DM) but were very evident by harvest. Varietal differences in other parameters, such as PIN, were of a similar magnitude throughout maturity. This study illustrates that dramatic changes in the relative and absolute concentration of various sorghum kernel constituents continue through physiological maturity. Continued changes, although less dramatic, were apparent through harvest. Varietal differences in chemical composition were readily apparent at physiological maturity suggesting that variety can affect feeding value of sorghum grain at any stage of harvest.

Experiment III

Reconstitution increased the IVDMD of the Darset (bird resistant) variety, usually within 2 to 4 days. Decreased tannin and PIN content may be responsible for this response. The IVDMD of varieties with a high initial digestibility (Dwarf Redlan and Redlan) was changed little by reconstitution. Changes in chemical composition for these varieties also were negligible. Reconstitution may be a highly effective method of increasing the feeding value of bird resistant varieties. The rapidity of the reconstitution response (5 days) observed in this study indicates that storage periods less than the traditional 21 days may be adequate for near maximal reconstitution response.

Experiment IV

Total tract starch digestibility tended to be the lowest for the dry rolled RED sorghum while nitrogen digestibility was lowest for the dry rolled BR. Ruminal fermentation of organic matter, starch and nitrogen tended to be lower for the dry rolled RED than the dry rolled HY or BR. Tannins in the BR sorghum were extensively degraded (95.2%) in the rumen. Reconstitution increased total tract starch and protein digestion, especially for the RED sorghum. The RED sorghum response, however, was primarily due to enhanced ruminal fermentation of starch and protein while the major response for the BR was in the small intestine. In both cases, starch digestion was very high (97.3% of that digested) at the ileum. In contrast, up to 15% of the digestible starch in the dry rolled RED sorghum was fermented in the large intestine. Reconstitution increased total N flow to the duodenum, primarily due to increased microbial N production. This study suggests that the

variety or type of sorghum grain can dramatically affect the site and extent of starch and protein digestion. In addition, reconstitution may enhance nutrient utilization through increased ruminal fermentation (RED) or through increased intestinal digestion and absorption (BR).

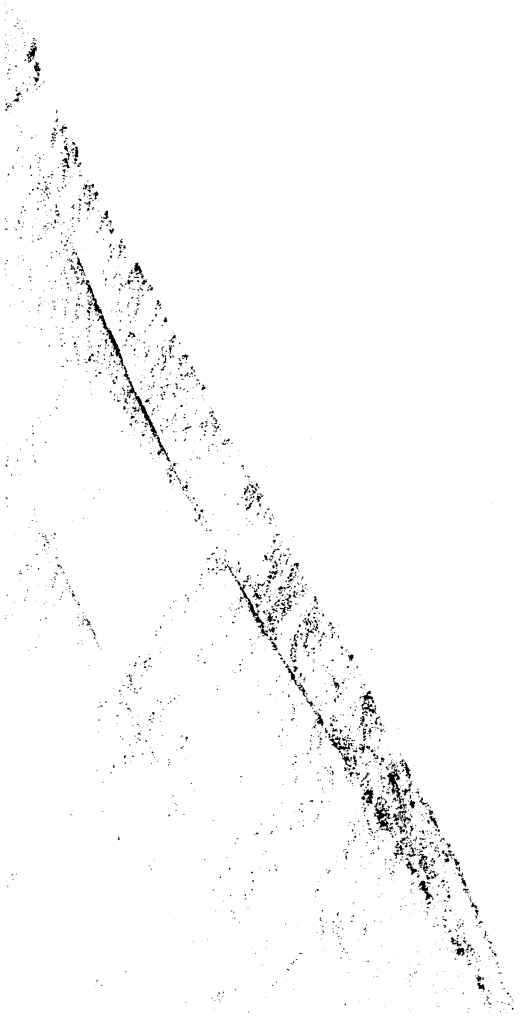
General Observations

Although this work provides information on several areas involving sorghum grain quality and utilization, further clarification of several points would enhance the value of this research. First, to fully evaluate the effect of nitrogen fertilization, the use of multiple levels of N might allow development of response curves and a better assessment of variety by nitrogen level interactions. Environmental conditions that could affect protein content or composition such as humidity, ambient temperature, moisture level and various soil nutrients should be more rigidly controlled. With regard to the maturity study, sorghum samples collected between 60 and 80% DM should be fermented to see if variety differences are translated into differences in feeding value. Reconstitution on a larger scale is necessary to insure that the trends observed for varieties and storage time are not merely a function of the system used in this study.

The nitrogen data from the steer trial might be better understood if dilution rate had been measured. Also, evaluation of particle size breakdown as grain particles pass through the digestive tract might enhance our knowledge of intestinal function. Future studies that would aid our understanding of sorghum grain variety or processing effects might include: (1) different grain processing techniques such as steam flaking to check response in different varieties and (2) further

investigation of high tannin sorghums to evaluate effects of tannin on site and extent of digestion.

Perhaps the greatest contribution that scientists involved in sorghum research could make would be to initiate a program to nutritionally evaluate the sorghum grain varieties or hybrids that are being produced. This and other work substantiates the theory that broad differences in the feeding quality of different sorghum grains exist. Evaluation of these sorghums in terms of chemical composition, digestibility and response to processing would allow the livestock producer to enhance production efficiency as well as to pressure seed companies to develop and maintain sorghum varieties of high nutritional value.



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VITA 2

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