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ANTINUTRITIONAL FACTORS IN SORGHUM: CHEMISTRY, MODE OF ACTION AND EFFECTS ON LIVESTOCK AND POULTRY

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ORIGINAL ARTICLE

ABSTRACT: *Sorghum basically contains two major anti-nutritional factors; tannin, a polyphenolic compound located in the grain and, dhurrin a cyanogenic glucoside located mainly in the aerial shoot and sprouted seeds. Tannins are high in sorghum with brown pericarp and no testa and very low in unpigmented grains. The main anti-nutritional effects of tannins are: reduction in voluntary feed intake due to reduced palatability, diminished digestibility and utilisation of nutrients, adverse effects upon metabolism and toxicity. The level of tannins present in sorghum seems to be the predominant factor that influences its nutritional value. Drying, soaking, grinding and pelleting appear to reduce tannin content in feedstuffs while diet supplementation with methyl group donors like choline and methionine reduce the problems associated with tannins in livestock. Dhurrin, on enzyme action readily yields hydrogen cyanide (HCN). The quantity of HCN in sorghum varies with cultivar and the growth condition but diminishes with age. Excess cyanide ion can quickly produce anoxia of the central nervous system through inactivating the cytochrome oxidase system and death can result within a few seconds. Making fodder into hay or silage however, destroys the poison.*

Key words: *Tannin, Dhurrin, Sorghum, Livestock, Poultry*

INTRODUCTION

Many plant components have the potential to precipitate adverse effects on the productivity of farm livestock (D'Mello, 2000). These compounds are present in the foliage and/or seeds of virtually every plant that is used in practical feeding. These compounds are often called anti-nutritional factors. Anti-nutritional factors are also those generated in natural feedstuff by the normal metabolism of the specie from original materials and by different mechanisms exert effects contrary to optimum nutrition (Chubb, 1982). Anti-nutritional factors may be grouped according to their mode of action as follows;

- Substances depressing digestion or metabolic utilisation of protein e.g. protease inhibitors, lectins (haemagglutinins), saponins and polyphenolic compounds
- Substances reducing or interfering with the utilisation of mineral elements e.g. Phytic acid, oxalic acids, gluccosinolates and gossypol
- Substances inactivating or increasing the requirements of certain vitamins e.g. Anti-vitamins A, D, E and K, anti-thiamine, nicotinic acid, pyridoxine and cyanocobalamin.

Some anti-nutritional factors may however exhibit more than one mode of activity (Liener, 1980; Jaffe, 1980; Chubb, 1982). Sorghum [*Sorghum bicolour (*L) Moench] is widely grown in the semi-arid and savannah regions of Nigeria. Maunder (2002) reported that sorghum is a traditional crop of much of Africa and Asia and an introduced and hybridized crop in the western hemisphere. It benefits from an ability to tolerate drought, soil toxicities and temperature extremes effectively than other cereals. Sorghum grains contain about 92.50% dry matter, 3270.00kcal/kg metabolisable energy for poultry, 9.50% crude protein, 2.55% ether extract, 2.70% crude fibre, 1.25% ash and 76.60% nitrogen free extract (NFE). Its protein is slightly higher than maize but as with most cereals deficient in lysine and tryptophan. More importantly, some varieties of sorghum grain have been reported to contain anti-nutritional factors chiefly tannin which binds proteins and impair digestion (Oyenuga, 1968; Aduku, 1993; Olomu, 1995; Tacon, 1995; Ngoka, 1997; Aletor, 1999. Aduku, 2004 and Etuk and Ukaejiofo, 2007).

This article discusses the chemistry, mode of action and effects of two important anti nutritional factors in sorghum; tannin and dhurrin on livestock and poultry.

ANTINUTRITIONAL FACTORS IN SORGHUM

Sorghum basically contain two important anti-nutritional factors, tannin, a polyphenolic compound located in the grain (Purseglove, 1972; Ologhobo et al, 1993; Kumar and D'Mello,1995) and the cyanogenic glycoside, dhurrin located mainly in the aerial shoot and sprouted seeds (Olomu, 1995; Oduguwa and Fafiolu, 2004).

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TANNIN: CHEMISTRY, DISTRIBUTION AND MODE OF ACTION

Chemistry

Tannins are water soluble polyphenolic heterogeneous compounds having molecular weight in excess of 5000 daltons and the ability to precipitate gelatine and other proteins from aqueous solution (de Lumen and Salamat, 1980; Singleton and Kratzer, 1973; Kumar and D'Mello, 1995). Tannins are generally considered to consist of polyphenolic systems of two types: the hydrolysable tannins (HT) (pyrogallol class), with esters of glucose and acids such as chebulic, ellagic, gallic and m-digallic and the condensed tannins (CT) (catechol tannins), based on leuco-anthocyanidin and like substances (Etherington and Roberts, 1982; Kumar and D'Mello, 1995). The pyrogallol tannins are readily hydrolysed by acids, bases and enzymes. Tannic acid, a gallotannin is a well known member of the group and contains 8-10 moles of gallic acid per mole of glucose (Fig.1). The commercial tannic acid has a chemical formula of $C_{76}H_{52}O_{46}$ though it contains a mixture of related compounds. Ellagitannins is another HT group member (Merck Index, 1976; Salunkhae et al, 1990; Kumar and D'Mello, 1995). HT is abundant in leaves, fruits, pods and galls of dicotyledons but not detected in monocotyledons (Lewis and Yamamoto, 1989). Condensed tannins are not hydrolysable and widespread, typically producing anthocyanidins on acid degradation. CT contains the familiar flavonoid skeleton, epicatechin and catechin linked together (Fig. 2). Flavan-3-ols and Flavan-3-4-diols linkages are commonly recognized (Porter, 1992; Salunkhae et al, 1990; Kumar and D'Mello, 1995). The pH has an effect on complex formation of tannin and protein. CT can react and form complexes by H-bonding with carbohydrates and proteins but at neutral pH form stronger bonds with proteins (McLeod, 1974). Condensed tannin in protein complex is stable and insoluble in the pH range of 3.5 – 7.0 but unstable and releases protein at pH of < 3.0 and >8.0 (Jones and Mangan, 1977). CT are widespread in legume forages (D'Mello, 1995) and sorghum (D'Mello, 2005).

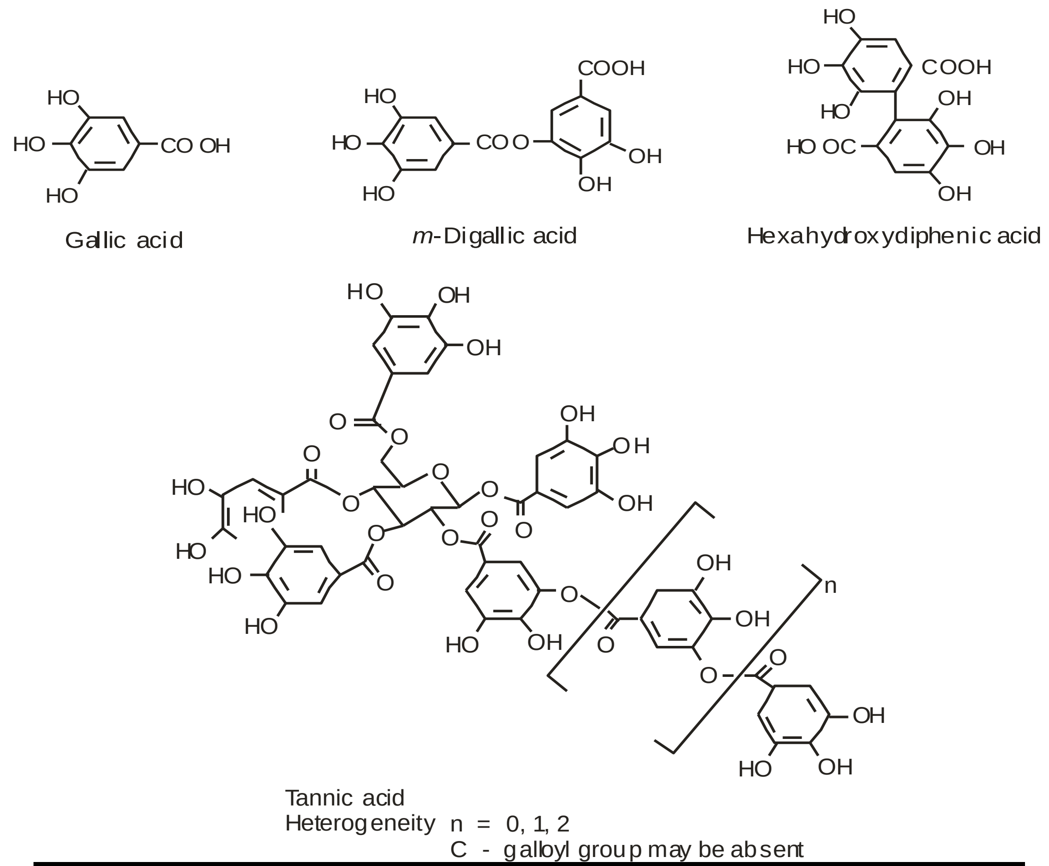

Fig. 1 - Constituents of hydrolysable tannin and structure of tannic acid (Source: Kumar and D'Mello, 1995)

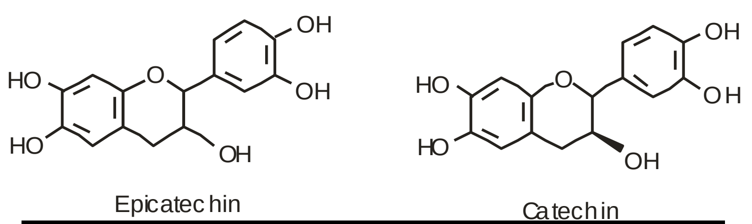

Fig. 2 - Constituent flavonoids of condensed tannins (Source: Porter, 1992).

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Distribution

Atteh (2002) reported that sorghum, especially the brown variety contains high levels of tannins and Purseglove (1972) opined that sorghum grain with testa contain tannins in varying proportion depending on variety, with certain strains containing up to 5%. It has been reported (Aningi et al., 1998) that polyphenols are high in sorghum with brown pericarp and no testa and very low in unpigmented grains. This characteristic has been utilised to develop sorghum varieties and hybrids to deter birds (Carter et al., 1989) because they are less palatable and tenacity of some bacteria is low (Schrägle and Müller, 1990). Etuk and Ukaejiofo (2007) reported 0.42% tannin content in brown coat coloured sorghum while Subramanian and Metta (2000) reported that the local Indian sorghum variety and ICSV 112 variety developed by ICRISAT and grown in India contain no tannins. 0.40% tannin was reported for samsorg 17, a variety previously coded (SSV) -3 (SK5912) and developed from local collections of Kaura through mutation breeding at the Institute of Agricultural Research (IAR), Samaru, Nigeria. ICSV 400, released by ICRISAT in 1996 recorded tannin value of 0.69% (IAR, 1995; NCGRB, 2004, Etuk, 2008). Red sorghum on the other hand contains about 23g/kg tannins which when reconstituted reduced to 16g/kg (Kumar et al., 2007).

Tannins are also found in soybean, sunflower seeds, faba beans and alfalfa and in browse plants like *Daniella oliveri* (Osakwe et al., 2004), sunflower seeds, *Leuceana leucocephala*, *Sesbania grandiflora, Acacia salicina* (Norton, 1994; D'Mello, 1995; Kumar and D'Mello, 1995). Drying, soaking, grinding and pelleting has been reported to reduce tannin content in feedstuffs while diet supplementation with methyl group donors like choline and methionine reduce the problems associated with tannins in livestock (Singleton and Kratzer, 1969; Atteh, 2002).

Mode of Action

Tannins reduce protein digestibility through the formation of complexes and the inhibition of activities of proteolytic enzymes in digestive secretions (Ahn et al., 1989; Kumar and D'Mello, 1995; Grosjean et al., 1999). The affinity of tannins for protein has been observed to increase with increase in molecular size of tannins. However tannins with extremely large molecular weight lose their affinity for protein and become insoluble (Kumar and Horigome, 1986). Proteins with high proline content impart an open structure which contains readily accessible sites for hydrogen bond formation with tannins (Hagerman, 1989). The polyphenols in brown sorghum may have a binding effect on minerals (Aningi et al., 1998).

Recent studies also revealed that polyphenols of the procyanidins (CT) have an antioxidant property (Corder, 2006) while tannic acid has anti-bacterial, anti-enzymatic and astringent property as well as constringing action upon mucous tissues. The ingestion of tannic acid causes constipation so it can be used to treat diarrhoea in the absence of inflammation (Phytolab, 2007).

EFFECT OF TANNINS ON LIVESTOCK

Ruminants appear to be more tolerant of CT than non-ruminants though ingestion of hydrolysable tannins can cause death (Ahn et al., 1989 and Norton, 1994). Condensed tannins present in legumes and browse trees according to Osakwe et al. (2000) may result in tannin protein complex formation and inhibit microbial attack. Primary effects of impaired rumen function, depressed feed intake, wool growth and live weight gains have been reported in sheep fed diets containing CT (D'Mello, 2000; Salem et al., 2005). Others are reduced palatability and diminished digestibility (D'Mello, 1982; Ola et al., 2005). Moderate levels of tannin (30 – 40g/kg legume dry matter) may however result in nutritional advantages in respect of increased bypass protein availability and bloat suppression in cattle (D'Mello, 2000). Feeding up to 30g/kg DM of wattle tannin extract nevertheless failed to show any improvement in protein status and therefore growth performance of goats to a considerable degree (Bengaly et al., 2007). Levels of CT above 60 – 100g/kg DM is considered to depress intake and growth (Bary and Duncan, 1984; van Hoven and Furstenburg, 1993). Feeding *Danielli oliveri* browse which contain 48g CT/kg DM to WAD sheep showed inhibitory effect on organic matter and detergent fibre digestibility (Osakwe, *et al.*, 2004). Tannin digestibility of 99.70% - 99.90% has been reported in goats fed *Tephrosia bracteoluta* which contains 0.40g of tannins (Ogungbesan et al., 2006).

Plant protein degradation in the rumen and decreased rumen availability of sulphur, which then depress the digestibility of plant cell wall has been reported (Norton, 1994). It is also possible that there is inhibition of microbial enzymes in the rumen and decreased availability of plant proteins for digestion in the intestine (Kumar and Singh, 1984; Bary and Duncan, 1984; Makkar et al., 1989). Binding of proteins to cell wall seem to be a factor in decreasing digestibility (Reed et al., 1990) and Kemalak et al. (2004) observed a negative relationship between tannin content of leaves and in vitro dry matter digestibility. Also, tannins diminish permeability of the guts wall by reducing nutrient flow. It also affects availability of amino acid and thus utilisation of protein (Ronstango, 1972; Eggum and Christensen, 1974; Mijavilla et al., 1977). Nevertheless, some ruminal microbes have been shown to possess the ability to metabolise tannins or at least remain active in a high tannin environment and may be used as inoculants to overcome detrimental effects of tannins in ruminants (Norton, 1994).

Increased levels of plasma growth hormones have been reported with increased intake of CT by sheep (Bary et al., 1986). Limited evidence indicates that tannins may have blood sugar and cholesterol lowering effect on rats. Wildens et al. (2004) reported lowered blood urea nitrogen and increased creatinine by goats and sheep fed diets containing 5% CT/kg/ DM. No effect was, however, observed on PCV and anthelmintic activity.

Earlier, D'Mello (2000) reported that higher levels of tannins (100 – 120 CT/kg legume DM) reduced gastrointestinal parasitism in lambs. Components and level of tannins tend to exert varied influences on blood constituents. Decreased blood levels of urea nitrogen and creatinine in rats fed epicatechin 3 - 0 - gallate and procyanidin B - 2 3, 3'-di-o-gallate up to 10mg/kg body weight have been reported (Yokozawa et al., 1991). However, 12.5mg of procyanidin C produced a significant increase in blood levels of urea nitrogen, creatinine and methylguanidine, a substance which accumulates in the blood with the progression of renal failures (Yokozawa et al., 1997).

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EFFECT OF TANNINS ON POULTRY AND PIGS

The main anti-nutritional effects of tannins are: reduction in voluntary feed intake due to reduced palatability, diminished digestibility and utilisation of nutrients, adverse effects upon metabolism and toxicity (Kumar and D'Mello, 1995; Atteh, 2002; Ola et al., 2005). These effects may be achieved via several mechanisms. Tannins exert inhibitory effect on a broad spectrum of digestive enzymes at several sites in the digestive tracts of poultry (Longstaff and McNab, 1991; Ahmed et al., 1991) and piglet (Jansman et al., 1993). In a study with broiler chickens, Iji et al (2004) reported that ideal digestibility of energy, protein, arginine and leucine were reduced as dietary tannin level rose to 20g/kg diet and beyond while methionine and phenylalanine were only negatively affected at tannin levels of 25g/kg diet. Protein efficiency ratio (PER) and net protein ratio are negatively correlated with tannic acid (Oke et al., 2004). Feed conversion efficiency increased with increasing level of tannin up to 15g/kg diet while pancreatic and jejenal enzymes activities were not affected. This suggests that a wider range of factors may be involved in regulating the effect of tannins on poultry (Iji et al., 2004).

Kumar et al. (2007) showed that tannin content of 16g/kg in red sorghum had no effect on nitrogen, calcium and phosphorus retention in broiler chickens. Similarly plasma albumin, globulin, protein, glucose, calcium, phosphorus, SGOT, SGTP and uric acid levels were not affected even at 100% replacement of maize with red sorghum. Mild histopathological changes in liver and kidney tissues as well as high cell mediated immune – response were, however, observed when raw red sorghum containing 23g tannins/kg were fed to the same group of broiler chickens. Elkins et al. (1978) reported that chickens fed high tannin sorghum developed leg abnormalities. Featherstone and Rogler (1975) showed that high tannin sorghum depressed growth in rats and chicken, which resulted from reduced protein and dry matter digestibility probably caused by interference of tannins with digestive action of trypsin and α-amylase either by binding the enzymes themselves or by combining with dietary protein to form indigestible complex. In laying birds, tannins decreased the rate of lay, adversely affect efficiency of feed utilisation and increase mortality (Rostangno et al., 1973; Guillaume and Belec, 1977). The level of tannins present in sorghum seems to be the predominant factor that influences its nutritional value (Vilijoen, 1998). Polyethylene glycol (PEG) when used as a dietary supplement can improve the nutritional value of high tannin feedstuff (Hewitt and Ford, 1982) while malting increases the protein, soluble sugars and reduces the tannin content of sorghum (Barrett and Larkin, 1974; Wu and Wall, 1980; Kubiezek et al., 1984). Boiling also reduces tannin content in taro cocoyam meals from 1.78mg/100g to 0.28mg/100g which resulted in negligible effect on carcass characteristics of broilers (Abdulrashid et al., 2007).

DHURRIN

Dhurrin is a cyanogenic glucoside which on enzyme action readily yields hydrogen cyanide (HCN) (Fig. 3, 4); it is located mainly in the aerial shoot of sorghum plant (Olomu, 1995; D'Mello, 2000). Dhurrin contains glucose of β-hydroxy-benzaldehyde cyanohydrin. Linamarin and amygdalin are other cyanogenic glycoside found in cassava, linseed and almonds respectively. Linamarin contains the glucose of acetone cyanohydrin while amygdalin contains glucose of benzaldehyde cyanohydrin (Chubb, 1982). Many commonly consumed legumes are also reported to be cyanogenic (Seigler et al., 1989). Cyanogenic glycosides when ingested and hydrolysed to free HCN cause cyanide toxicity (D'Mello, 1995). In Nigeria, HCN level of 15.18g/kg has been reported for malted sorghum sprouts (Oduguwa and Fafiolu, 2004).

Ruminants are more susceptible to HCN poisoning than horses and pigs but sheep appear less susceptible than cattle (Chubb, 1982). Hydrogen cyanide causes dysfunction of the central nervous system, respiratory failure and cardiac arrest. Metabolisable energy values for poultry tend to be lower in untreated cassava root presumably because of its cyanogenic potential (Keller, 1984; Tanner et al., 1990; D'Mello, 2000 and D'Mello 2005). The quantity of HCN in sorghum varies with cultivar and the growth condition but diminishes with age. Making fodder into hay or silage destroys the poison (Purseglove, 1972). Excess cyanide ion can quickly produce anoxia of the central nervous system through inactivating the cytochrome oxidase system and death can result within a few seconds (Chubb, 1982). Cyanide intake of up to 75.96mg/100g reduces apparent nutrient digestibility of broilers. Goats can also tolerate and degrade forage secondary metabolites below injury threshold (Ogungbesan et al., 2006). As little as 0.5g HCN is sufficient to kill a cow and more than 750ppm is regarded as dangerous to stock. Poor animal performance has also been reported as a result of cyanogens (Tanner et al., 1990).

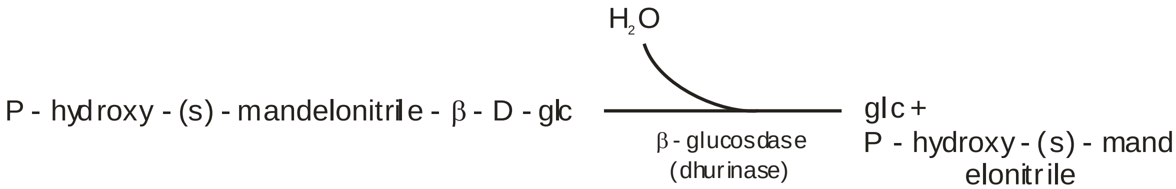

Fig. 3 - Hydrolysis of dhurrin by β-glucosidase (dhurrin). Source: Cicek and Esen (1998)

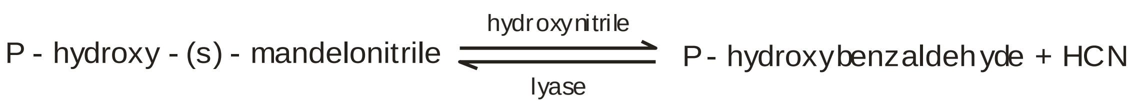

Fig. 4 - Production of hydrogen cyanide (HCN). Source: (Cicek and Esen, 1998)

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CONCLUSION

It would appear that the level of the anti-nutrients; tannin and dhurrin in sorghum and indeed other plant materials is a major determinant of the recognised effects on livestock and poultry. Similarly, the development of new varieties, age and processing seems to have an ameliorating effect on the content and intensity of toxicity of these anti nutritional factors in sorghum.

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