The Role of Polyphenols in Food-Type Sorghums

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Resumen: El nivel de polifenoles (fenilpropanoides, flavenoides, pigmentos antocianidínicos y taninos condensados) en grano de sorgo varía grandemente entre cultivares dado a que no tienen un papel directo en crecimiento y reproducción de la planta. Los polifenoles pueden servir para defender a la semilla contra hervíboros y patógenos. Los polifenoles frecuentemente disminuyen la aceptabilidad y/o valor nutricional del grano, por lo tanto, dichos compuestos han sido removidos de la semilla por medio de fitomejoramiento. Esto puede traer como consecuencia que el grano sea más vulnerable a plagas. Los polifenoles pueden impartir colores indeseables en los alimentos que contienen sorgo. Los taninos de los sorgos cafés pueden producir una sensación en la boca de sabor astringente, aunque este efecto puede ser disminuido por el cocimiento. Los sorgos altos en taninos tienen una calidad nutricional inferior a los sorgos bajos en taninos. Por lo tanto, producen menores ganancias de peso y eficiencias de conversión alimenticia en animales experimentales. Aunque estos efectos antinutricionales son usualmente atribuidos a la inhibición de la digestión de la proteína en el tracto digestivo, en experimentos con ratas se ha encontrado que hay más inhibición después de la digestión (metabolismo) que durante la misma. Los efectos antinutricionales de los taninos pudieran ser peores si no fuera por lo siguiente: a) proteínas salivales ricas en prolina que ligan a los taninos y por lo tanto disminuyen su afinidad por la proteína de la dieta y/o enzimas digestivas; b) la gran preferencia de los taninos por ligarse con proteínas fibrosas o de estructura abierta (gelatina) las cuales son generalmente deficientes en amino ácidos esenciales, en lugar de ligarse con proteínas globulares las cuales tienen generalmente más altos niveles de amino ácidos esenciales.

ABSTRACT

The level of polyphenols (phenylpropanoids, flavonoids, anthocyanidin pigments and condensed tannins) in sorghum grain greatly varies between cultivars because they have no direct role in growth or reproduction of the plant. Polyphenols may serve to defend the seed against herbivores or pathogens. Polyphenols often diminish the acceptability and/or nutritional

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value of the grain so they have largely been bred out of food-type sorghums, which may as a consequence be more vulnerable to pests. Polyphenol pigments may impart undesirable colors to sorghum-containing foods. Tannins in brown sorghums can produce an unpleasant astringent sensation in the mouth, although this effect is diminished on cooking. Sorghums rich in tannins are nutritionally inferior to low tannin sorghums, producing lower weight gains and feed efficiencies in experimental animals. Although the basis for these antinutritional effects is usually considered to be inhibition of protein digestion by tannins, in rat feeding trials we find more inhibition of post-digestion metabolism than of digestion itself. The antinutritional effects of sorghum tannins would be much worse if it were not for: a) Proline-rich tannin-binding salivary proteins which complex tannins and diminish their binding to dietary proteins and/or digestive enzymes; and b) The strong preference for tannin binding to fibrous, open-structured proteins (e.g., gelatin) which are usually deficient in essential amino acids, rather than compact globular proteins (often enzymes) which tend to have higher levels of essential amino acids.

Polyphenols occur in virtually all plant materials, including sorghum grain utilized for human food. The grain of some improved sorghum cultivars contains relatively low levels of polyphenols, mostly the phenolic acids such as ferulic acid (Hahn et al., 1980). Most sorghum cultivars contain other polyphenols such as flavonoids and anthocyanidin pigments. Some sorghum cultivars contain polymeric flavonoids, the condensed tannins, at levels which can exceed 3% (dry weight). When condensed tannins are present at these high levels, they are the predominant type of polyphenol in the grain (Butler, 1982). Most polyphenols are secondary metabolites, serving no essential metabolic function in growth or reproduction, so their presence or absence has little direct effect on the viability or productivity of the plant.

Sorghum polyphenols do have a beneficial effect on the plant by protecting it against herbivores, weathering, and preharvest germination (Butler, 1989). In many food-type sorghums most of the protective polyphenols have been bred out, possibly because of their negative effects on food quality as described below. Thus food-type sorghums are often more susceptible to pests than are their polyphenol-rich counterparts, which presumably more closely resemble the undomesticated progenitors of modern sorghums in this respect. Food-type sorghums are more difficult to produce in certain areas where pests (e.g., birds) are a severe problem. The sorghum producer has in effect assumed responsibility for protecting the crop in exchange for the improvement in food quality.

Polyphenols may adversely affect the palatability of sorghum-containing foods by producing unattractive colors, due to the presence of anthocyanidin pigments, or unpleasant tastes and/or astringent sensations, due to the presence of condensed tannins. In addition to these generally negative effects of sorghum polyphenols on the desirability of the foods produced from them, high-tannin "bird-resistant" sorghums, generally those containing a pigmented testa or undercoat, have long been recognized as nutritionally inferior to sorghums containing little or no tannin (Butler et al., 1986). Tannins from sorghum, as well as from other sources, bind very strongly to proteins (Butler et al., 1984). The diminished weight gains and feed efficiencies of experimental animals on high-tannin sorghum diets are partially due to inhibition of digestion of dietary proteins, possibly by combining with them to form a less digestible complex. Dietary tannins probably do not directly bind to digestive enzymes and inhibit them *in vivo* (Blytt et al., 1988).

Sorghum tannins do not interact equally with all proteins, but bind much more strongly to hydrophobic proteins with open, flexible structures, and especially to proteins rich in the amino acid proline (Hagerman and Bulter, 1981). The proteins in the sorghum seed which most strongly bind tannins are the major storage proteins, the prolamines (Butler et al., 1984). This selectivity is nutritionally beneficial, for it causes the proteins of poorest nutritional quality (because of their low levels of essential amino acids) to be more negatively affected by dietary tannin than are nutritionally superior proteins which bind tannin less strongly. In effect, nutritionally inferior proteins are sacrificed to tannin binding, protecting more valuable proteins. In this respect, addition of tannin to an animal diet has been reported to result in an <u>increase</u> in the "biological value" of the diet (Eggum and Christensen, 1973). These effects, which tend to diminish the possible severity of antinutritional properties of tannins, may extend to animal proteins in tannin-containing diets. The major animal protein, collagen, binds tannin very strongly due to its open conformation and its high level of hydroxyproline, but it is relatively poor in essential amino acids.

In recent (unpublished) experiments in which the nutritional effects of high-tannin sorghums on rats were analyzed in a novel manner which distinguished between effects on digestion/absorption and on post-digestive metabolism, we found that the major effect is on metabolism after digestion/absorption, rather than on the actual process of digestion. In this respect dietary tannin seems to function as a metabolic poison in these animals. These observations suggest that some (polyphenolic?) component of high-tannin sorghums is absorbed from the digestive tract and transported to sites where it interfers with crucial metabolic reactions. These studies are being extended in hopes of identifying the vulnerable metabolic process. Presumably these observations are relevant to the effects of dietary tannins on human and livestock nutrition.

With our colleagues we have shown that in laboratory rats and mice, dietary tannins induce hypertrophy of the parotid glands and induce production of unique salivary proteins containing up to 45% proline (Mehansho et al., 1983). As expected from their proline content, these proteins bind protein very strongly (Hagerman and Butler, 1981), and we have suggested that they constitute an important metabolic defense against dietary tannins by selectively binding (and thus inactivating) tannins as they enter the digestive tract (Mehansho et al., 1987). Our survey of a wide range of herbivores, omnivores and carnivores suggests that virtually all animals that consume plant materials, including man, produce these proline-rich, tannin-binding proteins (Mole and Butler, personal communication). In most cases these defensive proteins are constitutive rather than induced by dietary tannin.

Hamsters represent a curious exception; although they carry genes specifying these proteins, and although these proteins can be induced by treatment with isoproterenol, a beta-antagonist drug, hamsters are unable to produce these proteins in response to dietary tannin (Mehansho et al., 1987). Hamsters are extraordinarily vulnerable to dietary tannin; they are rapidly killed by levels of tannins to which rats readily adapt (Mehansho et al., 1987), confirming the importance of salivary proline-rich proteins as a defense against dietary tannins. Rats fed appropriate levels of propranolol or other beta-antagonist drugs cannot respond to dietary tannin by producing these defensive salivary proteins, and become much more vulnerable, similar to hamsters. These observations suggest that dietary tannins would produce much more severe antinutritional effects if it were not for the defensive system of specialized salivary proteins produced by animals which consume tannins.

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