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Selection and storage of cereal grains for livestock

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INTRODUCTION

A six-year research program, "Premium Grains for Livestock", funded by the Grains R&D Corporation, several animal R&D Corporations and Ridley Agriproducts is focussed on improving the quality of cereal grains for livestock. Cereal grains provide the major source of energy for animals raised in intensive production systems. However, the energy available from cereal grains can vary widely between both grain and animal species. For example, the digestible energy (DE) content of wheat and barley for pigs has been reported to range from 13.3 to 17.0 and from 11.7 to 16.0 MJ/kg, respectively (van Barneveld, 1999). Similarly, Hughes and Choct (1999) reported a range in apparent metabolisable energy (AME, MJ/kg) for broiler chickens from 10.4 to 15.9 MJ/kg for wheat, 10.4 to 13.5 for barley and 8.6 to 16.6 for triticale. There are also large differences between animal species in their capacity to digest starch in cereals. Sorghum starch is almost completely digested by poultry, compared with significant excretion of sorghum starch in the faeces of cattle (Rowe *et al*. 1999). A primary aim of the research is to identify the chemical, physical and morphological characteristics of grains that determine their nutritional value for sheep, cattle, pigs and poultry.

RESEARCH STRATEGIES

Over 2000 grains with a wide range in chemical and physical characteristics thought to influence nutritional value have been collected. Grains were obtained from germplasm archives, plant breeders collections or selected because of suspected wide variation in nutritional value due to severe drought, frost damage or pre-harvest germination. All grains have been scanned with near infra-red spectrometry (NIR) and the extent of digestion of components of selected grains examined within *in vitro* systems simulating rumen fermentation and intestinal digestion. A subset of approximately 100 grains selected on the basis of NIR scans and *in vitro* analyses have been fed to animals including sheep, cattle, pigs, broiler chickens and laying hens. A relatively small number of grains have been offered to all animal types. The impact of storage and processing of grains on the energy available to animals is being examined.

THE ENERGY VALUE OF CEREAL GRAINS

The available energy content of several individual grains offered to sheep, cattle, pigs, broiler chickens and laying hens is shown in Table 1. There were relatively small differences in the available energy content for most individual grains when compared across the animal types. For example, the values for Reinette barley ranged from 12.63 MJ/kg for broiler chickens to 13.56 MJ/kg for cattle. Wheat showed a higher energy content for pigs than for the other animal species. The most striking differences between animal types were for the Merlin cultivar of barley and for sorghum. Merlin is a hull-less cultivar with low amylose starch. It had the highest available energy content when offered to sheep and pigs (>15.3 MJ/kg), but was poorly utilised by poultry (12.6 MJ/kg). Similarly large differences occurred for sorghum which was poorly utilised by catttle where the energy content of a normal sorghum isoline was only 60-61% of that for pigs and broiler chickens. The energy content for cattle of a waxy, low amylose isoline was substantially greater than that of the normal isoline (13.21 MJ/kg digestible energy compared with 9.73 MJ/kg), but was only 80-82% of the value for pigs and chickens.

Table 1. Available energy content of individual grains (MJ/kg DM) fed across animal as digestible energy for sheep, cattle, pigs, and apparent metabolisable energy for poultry.

Grain	Sheep	Cattle	Pigs	Broilers	Layers
Sorghum					
Waxy isoline	14.56	9.73	16.06	15.90	15.48
Normal isoline	14.79	13.21	16.40	15.98	15.96
Sprouted	14.53	10.17	16.43	16.08	15.38
Barley					
Reinette	13.04	13.56	13.30	12.63	13.00
Arapiles frosted	11.51	11.91	11.70	11.68	11.12
Galleon	13.59	13.51	14.89	13.20	13.91
Merlin	15.50	-	15.33	12.60	-
Wheat					
Janz	13.86	13.84	15.32	13.84	13.53
Sunstate	14.31	14.23	15.97	14.22	14.27
Triticale					
Tahara frosted	12.26	12.44	12.00	11.21	11.43
Tahara	13.66	13.74	13.85	14.36	14.22
Oats					
Numbat (naked)	15.90	-	-	14.55	16.18
Yarran	13.41	13.33	-	13.37	14.08
Echidna	12.56	12.38	-	12.55	12.71

REASONS FOR THE DIFFERENCES BETWEEN GRAINS AND ANIMALS

The extent of grain digestion by animals depends on the availability of enzymes capable of breaking the specific chemical bonds of each grain component, the ability of the enzymes to come in contact with the bonds and the length of time the enzymes are in association with the substrates. Glucose units, which contribute the main energy source, are commonly linked by α-(1-4), α-(1-6), β-(1-4) or β-(1-6) glycosidic bonds. The first of these, found predominantly in starch, can be cleaved by digestive enzymes from animals, whereas the β-(1-4) linkages, found in cellulose, requires microbial enzymes for cleavage. The α-(1-6) glycosidic linkages also restrict the action of animal amylases. The predominance of either the α-(1-4) or β-(1-4) bonds within a carbohydrate has a marked effect on energy availability to animals depending on their digestive systems. Starch is composed of two main compounds, amylose and amylopectin. Amylose consists primarily of long chains of α-(1-4) linked glucose units that form a tight helical structure, whereas amylopectin contains some α-(1-6) linkages that produce branches in the molecule and provides an open structure that is more readily attacked by digestive enzymes. The β-(1-3, 1-4) bonds found in β-glucans, xylans and arabinoxylans also are resistant to digestion by animal enzymes but can be degraded by microbial enzymes.

Grains consumed by ruminants are first exposed to microbial enzymes, which digest fibrous structures, starches and proteins before passing to the small intestine where they are exposed to animal secreted amylases, proteases and lipases. Alternatively, grains fed to pigs and poultry are first exposed to animal enzymes and, with pigs, then to microbial enzymes in the hind-gut. Microbial enzymes play little part in the digestion process in poultry, but the gizzard causes substantial structural modifications to grain cell walls as the grain passes through the digestive tract.

The accessibility of an enzyme to a grain component can be affected by particle size and surface area, physical barriers like cell walls or chemical barriers such as the tight helical structure of amylose chains, hydrophobic properties of lipid molecules or the digestibility of proteins. The rate of passage of digesta through the digestive tract can affect the time enzymes are associated with the grain components and thereby alter the extent of digestion. The main factors that contribute to differences in the nutritional value of grains are discussed.

Gross chemical composition of the grain

The amount of energy available to an animal from a grain depends on the relative proportion of each chemical constituent, its energy contents and the extent of digestion. The chemical composition of all grains fed to animals within the Premium Grains Program has been determined and the gross energy content of these constituents is known. The extent of digestion of each component depends on the chemical component and the enzymes available. The relatively low available energy content of the heavily frosted sample of Arapilies barley grain shown in Table 1 can be explained largely by its high fibre and low starch content. Similarly, the high digestibility of the hull-less barley, Merlin, in sheep and pigs is due to the low fibre and high starch content.

Endosperm cell wall composition and thickness

Endosperm cell walls are composed of a cellulose skeleton impregnated with soluble and insoluble arabinoxylans and β-glucans. Although these cell walls have little effect on the availability of energy from cereal grains for ruminants, they can reduce the contact of amylolytic enzymes with starch granules and lower energy availability for non-ruminant animals by acting either as a physical barrier or by increasing the viscosity of the digesta. Endosperm cell walls act more as a physical barrier for pigs than for poultry. Grains eaten by birds are subjected to intense grinding in the gizzard and most endosperm cell walls are ruptured. However, pigs rupture few cells during mastication and the energy available from cereal grains is increased markedly by fine grinding (Wondra *et al*. 1995).

Choct and Annison (1990) observed a linear decline in broiler AME from 17.5 MJ/kg for rice to 11 MJ/kg for rye with increasing soluble NSP content of grain. Soluble NSP compounds increase the viscosity of digesta, reduce the diffusion of digestive enzymes and reduce the rate of substrate digestion. Choct and Annison (1992) demonstrated that the chain length of soluble NSP polymers was more important for reducing AME of wheat for broilers than was the total soluble NSP content, because of the greater increase in digesta viscosity, which reduced the digestion of starch, amino acids and fatty acids.

Protein matrix surrounding starch granules

Starch granules in the endosperm of cereal grains are imbedded to varying degrees in a protein matrix. In sorghum, the protein matrix forms a contiguous layer around individual starch granules. These proteins must be degraded to expose the starch to amylases. The protein matrix in sorghum grain contains a high concentration of γ-kafirins with many disulphide bonds, which are resistant to some enzymes (Rooney and Pflugfelder 1986). There is strong evidence that the low availability of energy from sorghum grain for cattle is due to inaccessibility of amylolytic enzymes to the starch granules embedded in the protein matrix (Black *et al*. 2001). The marked difference in digestion of sorghum starch between cattle compared with pigs and poultry is due to differences in the capacity of proteases to degrade the protein matrix.

Starch composition

The tight helical structure of the amylose molecule of starch makes it less accessible to amylases than amylopectin with its branched α-(1-6) linkages. The effect of the proportion of amylose in starch on the *in vitro* enzyme digestion of starch for several grains has been examined in the Premium Grains for Livestock Program. The results confirm that the digestibility of starch is increased as the amylose content declines. Pettersson and Lindberg (1997) observed in pigs a significantly higher digestibility in the small intestines of starch when amylopectin rich barley (9:91, amylose:amylopectin) was compared with normal barley (30:70, amylose:amylopectin).

Other characteristics of grains

There is evidence that the digestibility of oat grain is influenced significantly by the characteristics of the hulls. The whole tract digestibility in sheep of four cultivars of oats grown in the same location was found to vary from 62.4 to 76.2 % and was associated closely with the lignin content of the grain. All high lignin oats have low digestibility, whereas the digestibility of low lignin oats can be either high or low and is thought to be due to the content of phenolic acids and the proportions of ester and ether bonds. There is evidence that grain hardness and hydration capacity have a positive effect on the energy available to cattle, but a negative effect on the energy for poultry.

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