

# Nutritional Value of Cereal Grains for Animals

**J.L. Black**

*John L Black Consulting, Locked Bag 21, Warrimoo, NSW 2774, Australia*

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## Abstract

The energy value of cereal grains for livestock varies widely between grains and animal species. For example, the digestible energy content for pigs of wheat and barley grain ranges from 13.3 to 17.0 MJ/kg and 11.7 to 16.0 MJ/kg, respectively <sup>1</sup>. However, the digestible energy content of sorghum grain for pigs shows little variation from 17.0 to 18.0 MJ/kg. Hughes & Choct <sup>2</sup> reported a similar wide range across some grains in apparent metabolisable energy (AME) values for broiler chickens, being from 10.4 to 15.9 MJ/kg for wheat, 10.4 to 13.5 MJ/kg for barley and 8.6 to 16.6 MJ/kg for triticale. The chicken AME values for sorghum and maize, again, show a small range from only 15.6 to 16.1 MJ/kg, with a similar small range for oat grain (11.8 to 12.4 MJ/kg). Significant variation exists between grains in the digestibility of starch within the rumen of cattle, being 0.92 for oat grain, 0.65 for maize and 0.62 for sorghum starch <sup>3</sup>. There are also striking differences between animal species in their capacity to digest cereal starch. The digestibility of sorghum starch across the whole digestive tract of poultry is extremely high (0.99) compared with 0.87 for cattle and 0.30 for horses <sup>3</sup>. Reasons for these observed differences in the energy value of cereal grains are discussed.

## Determinants of energy digestibility

Cereal grains consist of an embryo and scutellum surrounded by the endosperm containing cells packed predominantly with starch granules embedded in a protein matrix. The endosperm cell walls are composed mainly of arabinoxylans in wheat and predominantly (1-3,1-4)- $\beta$ -glucans in barley and oats, respectively. An aleurone layer, which is composed of thick walled cells rich in protein and lipid, surrounds the endosperm. The outermost layers of the grain are the testa and the multi-layered pericarp consisting mainly of cellulose and lignin. In some grains, such as barley and oats, the hulls adhere closely to the pericarp and are not removed during threshing. The energy within these grain components becomes available to an animal only when the large molecules are digested and the released sub-units absorbed. Digestion depends on the availability of enzymes capable of breaking specific chemical bonds, the ability of the enzyme to come in contact with the bonds and the length of time the enzymes and substrate are in contact.

Glucose units in grain components are commonly linked by  $\alpha$ -(1-4),  $\alpha$ -(1-6) or  $\beta$ -(1-4) glycosidic linkages. The former, found predominantly in starch, can be hydrolysed by animal digestive enzymes, whereas the  $\beta$ -(1-4) linkages, found in cellulose, require microbial enzymes for cleavage. The  $\alpha$ -(1-6) glycosidic linkages also restrict the action of animal amylases. The predominance of either the  $\alpha$ -(1-4) or  $\beta$ -(1-4) glycosidic linkages have a marked effect on energy availability to animals. Enzymes for the hydrolysis of the non-starch polysaccharides (NSP) such as arabinoxylan and (1-3,1-4)- $\beta$ -glucans, are not produced in the digestive tract of animals, however they are secreted by bacteria in the lower alimentary tract. Lignin consists of phenolic polymers that are indigestible to animal enzymes and most intestinal microbes. Lignin can bind covalently to other plant cell wall polysaccharides and proteins rendering them less accessible to digestive enzymes.

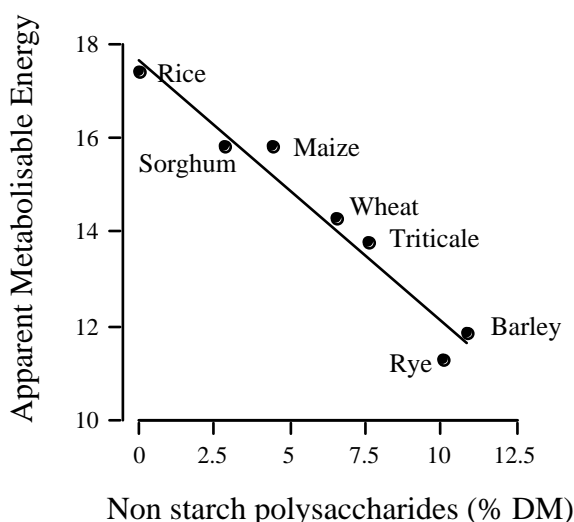
Cereal grains contain few free sugars, mainly sucrose and fructose, which are readily digested. Starch is degradable by intestinal enzymes, but there is considerable variation in the capacity of animals to digest starch in the small intestines. Starch which passes to the large intestine is termed 'resistant starch' and is fermented by micro-organisms with a lower energy value to the animal because of energy loss through the heat of fermentation, methane and a reduced efficiency of use of the absorbed volatile fatty acids compared with glucose. The susceptibility of starch to intestinal digestion depends on characteristics of the starch molecule and accessibility of the starch granules to intestinal amylases. Factors contributing to resistant starch include:

- a) *Amylose:amylopectin ratio* Starch is composed amylose and amylopectin. Amylose consists of long chains of  $\alpha$ -(1-4)-linked glucose that form tight helical structures and are relatively inaccessible to amylases, whereas amylopectin contains some  $\alpha$ -(1-6) linkages that produce branches in the molecule and provide an open structure more readily attacked by digestive enzymes. High amylose starches are poorly digested compared with starches containing mainly amylopectin. Pettersson & Lindberg <sup>4</sup> measured in pigs a significantly higher digestibility in the small intestines of starch when the animals were fed amylopectin rich barley (9:91, amylose:amylopectin) compared with conventional barley (30:70, amylose:amylopectin). Similarly, Granfeldt et al. <sup>5</sup> found in rats that digestion in the small intestinal of starch from low amylose, dent maize was 0.96 compared with 0.68 for high amylose maize.
- (b) *Amylose-lipid complexes* Lipid molecules are frequently located within the amylose helix of cereal starches. The hydrophobic nature of lipid is believed to inhibit amylase accessibility to the starch molecule and reduce starch digestibility <sup>6</sup>.
- (c) *Protein-starch matrix* Starch granules are imbedded to varying degrees in protein matrix and, in some grains like sorghum, protein bodies can form a contiguous layer around the outer edge of the endosperm. These proteins must be degraded to expose the starch fully to amylases. The degree to which the granules are encapsulated, the presence of proteases and anti-nutritional factors like tannins and trypsin inhibitors will affect starch digestion. The protein matrix surrounding the starch granules in maize and sorghum grain contains a high concentration of  $\gamma$ -kafirins with many disulphide bonds which are particularly resistant to enzyme attack <sup>7</sup>. The marked difference in digestion of sorghum and maize starch between herbivores like cattle and horses compared with pigs and poultry could be due to differences in the capacity of their proteases to degrade the protein matrix.
- (d) *Grain pericarp, cell walls and particle size* The accessibility of starch to amylases can be limited by the outer fibrous layers of the grain and the cell walls within the endosperm. Rupture of these structures by chewing, the grinding action of the crop (upper section of the digestive tract) in poultry or processing is important for increasing the digestibility of grain within the small intestine. The fineness of the particles affects the surface area of starch available to enzyme attack and significantly affects grain digestibility in pigs.

Soluble  $\beta$ -glucans, xylans and arabinoxylans (non-starch polysaccharides, NSP) can account for 6-12% of the dry matter in wheat, triticale, rye and barley, 2-4% in sorghum and maize, and less than 1% in rice. Choct & Annison <sup>8</sup> 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 (Figure 1). This marked change in energy availability between the grains could not be explained by differences in the efficiency of use of the energy from NSP if they were digested by microbes in the hind-gut. Some of the observed effect may have resulted from the high NSP content reducing cell wall breakdown and access of amylases to the starch granules. However, there is substantial evidence suggesting that soluble NSP compounds increase the viscosity of digesta, reduce the diffusion of digestive enzymes and reduce the rate of substrate digestion. Choct & Annison <sup>9</sup> demonstrated

that the chain length of soluble NSP polymers was more important for reducing the AME value of wheat for broilers than was the total soluble NSP content, because the increase in digesta viscosity reduced the digestion of starch, amino acids and saturated fatty acids. Choct & Hughes<sup>10</sup> found that the AME content of 'new season' wheat can rise by 1 MJ/kg after storage for 6 months because of the endogenous breakdown of soluble NSP polymers to smaller chain lengths.

**Figure 1:** The relationship between Apparent Metabolisable Energy (MJ/kg DM) and the soluble NSP content (% of DM) of grains in broiler chickens<sup>8</sup>.



## References

1. R.J. van Barneveld, *Aust. J. Agric. Res.*, 1999, **50**:(In Press).
2. R.J. Hughes and M. Choct, *Aust. J. Agric. Res.*, 1999, **50**:(In Press).
3. J.B. Rowe, M. Choct and D.W. Pethick, *Aust. J. Agric. Res.*, 1999, **50**:(In Press).
4. A. Petterson and J.E. Lindberg, *Anim. Feed Sci. Tech.*, 1997, **66**,97.
5. Y.E. Granfeldt, A.W. Drews and I.M.E. Bjorck, *J. Nutr.*, 1993, **123**,1676.
6. N. -G. Asp, J.M.M. van Amelsvoort and J.G.A.J. Hautvast, *Nutr. Res. Rev.*, 1996, **9**,1.
7. L.W. Rooney and R.I. Pflugfelder, *J. Anim.Sci.*, 1986, **63**,1607.
8. M.Choct and G. Annison, *Br. Poultry Sci.*, 1990, **31**,811.
9. M.Choct and G. Annison, *Br. Poultry Sci.*, 1992, **33**,821.
10. M.Choct and R.J. Hughes, *Recent Advances in Animal Nutrition*, University of New England, Armidale. 1997, p. 146.

**John L Black** (B.Agric.Sci., Dip.Ed., PhD., FTSE) is Director of John L Black Consulting a Research Management consulting company and co-ordinator of the collaborative Premium Grains for Livestock Program funded jointly by the Grains Research & Development Corporation, Meat and Livestock Australia, Pig Research & Development Corporation, Dairy Research & Development Corporation and the Rural Industries Research & Development Corporation's Chicken Meat and Egg Programs.