Getting to know

Improving feed quality for the benefit of the poultry farmer can be a demanding task, especially where even small improvements in performance are difficult to achieve. Going back to the basics of starch digestion shows how improvements in our relationship with one of the more familiar feed components can improve growth and health.

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Starch is an important source of energy for monogastrics. Around 70% of the value of the raw materials incorporated into a diet is determined by their starch content. In broiler diets it supplies more than 50% of the apparent metabolisable energy. Thus, a correct evaluation of the nutritional value of starch is important for optimal feed formulation.

In most feed evaluation systems for broilers, it is incorrectly assumed that the starch in the common raw materials in broiler feeds is completely digested in the small intestine. The effect of technological treatment during compound feed production, the origin of the starch and the variation within the raw materials are not taken into account. The rate of digestion of the starch in a diet may also affect energy utilisation of the diet. Based on the observation that technological treatment of starch may cause the formation of starch that is not susceptible to enzymatic hydrolysis (resistant starch), a research project was initiated with three objectives. Firstly, the effects of production processes in the compound feed industry were investigated in terms of their effects on the digestibility of starch in broilers. Secondly, an in vitro measurement of starch digestibility in broiler diets was developed; and thirdly, the project aimed to determine the kinetics of starches from different origins: cassava, maize, wheat, sorghum and peas.

Resistance matters

The resistance of starch to enzymatic degradation is determined by its molecular structure, which in turn is dependent on the origin of the starch and the treatments to which it has been exposed. Starch is a plant storage carbohydrate, found in grains of varying size. It is made up of two glucose polymers: amylose and amylopectin. Amylopectin, the major component of starch, is a branched molecule which gives the starch granule a certain degree of crystallinity. This molecular structure can be modified by treatments in which heat and moisture are involved. During such treatment, the crystalline structure gives way to an amorphous one—a process known as gelatinisation. Gelatinised starch is more prone to digestion by digestive enzymes (eg. amylose), because the accessibility of its structure to enzymes is increased. However, starch digestion is not only determined by the properties of the starch fraction itself. Accessibility is also governed by the cell-wall and protein structures that surround the starch granules and can protect starch granules from degradation by digestive enzymes, through simply restricting their access to the starch molecules. If particle size is reduced by milling, the influence of these structures is reduced and the surface area per gram increases, resulting in more rapid digestion.

Influence of raw materials in practice

In an experiment at the Institute for Animal Nutrition, “De Schothorst” in Lelystad, the Netherlands, the digestion of starch from a variety of native feedstuffs was measured in different parts of the small intestine of 28-day old broilers. Diets were formulated containing rapidly and or slowly digestible starch sources so that the influence of starch source on digestion in different parts of the small intestine could be evaluated. Differences between raw materials were observed in site, rate and extent of starch digestion. It was also observed that the starch from some feedstuffs was not completely digested at the end of the small intestine. The majority of the starch was digested in the anterior part of the small intestine, where differences were also more pronounced. Legumes like peas and beans contained a considerable starch fraction that was digested in the second half of the small intestine. Total starch digestion was not limited by retention time in the gastrointestinal tract for most feedstuffs. However, for most feedstuffs with slow starch digestion, like legumes and potato starch, retention time appeared to limit the total extent of starch digestion. Microbial fermentation of starch that was not digested in the small intestine did not occur in the hindgut, as total starch digestion was similar to ileal starch digestion.

Model development

An in vitro method that simulates the digestive processes in the broiler alimentary tract was developed to look at broiler diets based on raw materials known to have different rates of starch digestion. In vitro starch digestion correlated well with site, rate and extent of the in vivo study mentioned above. The in vitro starch digestion results were found to be additive. Based on in vitro measurements, starch could be categorised into three distinct fractions: rapidly digestible starch (RDS); slowly digestible starch (SDS) and resistant starch (RS). The starch digestion curves of legumes and waxy maize...
were found to fit better into a two-phase model than a single-phase model. This suggests that two distinct starch fractions are digested at different rates. This was also noticed in compound feeds containing more than one starch source. Both in vivo and in vitro measurements indicated major differences in starch digestion rate between feedstuffs. However the practical relevance of starch digestion rate in broiler nutrition was unknown.

In another experiment, the rate of starch digestion was varied by using different raw material composition or technological treatments, such as pelleting and expanding. Both pelleting and expanding were found to increase the rate of starch digestion in all the starch sources used. The starch digestion rate of diets containing steam pelleted starch sources was higher than that of untreated starch sources and the starch digestion rate of the expander-pelleted starch sources was the highest. The pellets were milled coarsely before mixing with the other dietary components. The starch sources from each sub-batch were included in six experimental diets: unprocessed pea/maize; steam-pelleted pea/maize; expander-pelleted pea/maize; unprocessed cassava/wheat; steam-pelleted cassava/wheat and expander-pelleted cassava/wheat. Due to differences in particle size distribution, no clear statements could be made regarding feed intake and weight gain. However, the positive effect of SDS on feed efficiency was confirmed. Feed efficiency was better for broilers on untreated mash diets with peas and maize (high SDS content) compared to those on untreated mash diets with cassava and wheat (high RDS content) or with expander-treated peas and maize. In both cases, starch digestion rate was substantially higher than for unprocessed peas and maize, as would be expected for RDS sources.

Protein digestion improved by SDS
Furthermore, with regard to feed efficiency, an interaction was observed between starch digestion rate and amino acid level. Feed efficiency improved when additional amino acids were included in a diet containing RDS, but not when they were added to a diet containing SDS. This suggests that diets with high levels of SDS lead to lower amino acid requirements. In a further experiment, five different levels of amino acids were incorporated into diets with either SDS (a pea/maize diet) or rapidly digestible starch (a cassava/wheat diet). Across all amino acid levels, weight gain was higher and FCR lower for birds fed the SDS diets than for those give the RDS diets. The difference in weight gain and FCR was most pronounced at the lowest level of amino acids included. This interaction between starch digestion rate and amino acid level is in accordance with those of the previous experiment.

Benefits of slow digestion
The positive effect of slowly digestible starch on feed efficiency and the observation that the effect was most pronounced at low amino acid levels suggests that protein efficiency is higher when slowly digestible starch is fed, as opposed to rapidly digestible starch. Slow starch digestion results in more-or-less continuous glucose release to the bloodstream and as a result insulin is also released gradually over a longer period. Insulin regulates the transport and uptake of amino acids. When the amino acid supply is sufficient, a prolonged period of elevated plasma insulin level results in a greater incorporation of amino acids into protein. Another consequence of slow starch digestion is that part of the starch is digested in the posterior part of the small intestine. Oxidation of the glucose that is absorbed in this region fuels the metabolism of the intestinal epithelium. Other energy sources for the intestinal wall are amino acids such as glutamine. When glucose is not available to the distal small intestinal epithelium, additional amino acids may be oxidised (by gluconeogenesis) to meet their energy (glucose) demands. This may be the case when diets containing mainly rapidly digestible starch sources are fed to broilers.

The results of the two experiments in which the response of broil-
ers to varying levels of starch digestion rate was investigated suggest
that the performance is affected by the rate of digestion of the
starch, with in a certain range of starch digestion rate. The FCR of
broilers responds to increasing levels of starch digestion rate accord-
ing to a sigmoid curve. Beyond a certain threshold, the amount of
slowly digestible starch is too low to have a positive effect on FCR.
Within a certain range, however, FCR improves when the rate
increases. Below a lower threshold, FCR is not affected, or may even
be increased due to impaired ileal starch digestion. These low starch
digestion rates are not expected to be found in pelleted feeds and
the feedstuffs that are used in commercial broiler diets have higher
starch digestion rates.

The practical relevance
Based on our experiments at “De Schothorst”, it can be concluded
that starch digestion rate has relevance in practical broiler nutri-
tion. Starch digestion is often less than 100%, especially in broilers.
The poultry nutritionist should therefore be aware of the differ-
ences in starch digestion rate between feedstuffs as this has conse-
quences for their energy value to broilers. Starch digestion rate can
be increased, but not decreased, by processing in the feed mill.
Therefore, the process engineer should also be aware of the conse-
quences of preconditioning and pelleting conditions on starch
digestion rate. The in vitro method described above is an effective
tool to predict quantitative differences in the rate of starch diges-
tion between raw materials and after different processing methods.
From in vitro and in vivo experiments, SDS was found to improve
performance, although this property was lost after expanding. SDS
also appears to have a protein-sparing effect when used in meal-fee-
ing systems, because of the reduction in gluconeogenesis occurring
to provide energy for the distal small intestinal epithelium. Finally,
the composition of the intestinal microflora was found to be affect-
ed by starch degradation rate. This may prove useful when formulat-
ing diets without the use of antibiotic growth promoters.

The digestion coefficients described above were, however, deter-
mined in four-week-old broilers. It is known that digestive capacity
is not yet optimal in the young chick. The digestive system may still
be developing or the bird may still be adapting to the starch-rich
diets it is fed. Contradicting effects of starch digestion rates on per-
formance of young birds may be explained by the fact that their
starch digestion capacity is not yet optimal. Therefore, another in
vitro protocol is required to predict starch digestion in these young
birds.

From digestion to resistance- the next step?
In the course of our experiments into starch digestion kinetics and
performance parameters in broilers, a positive correlation was
observed between slowly digestible starch and resistant starch. If
diets containing slowly digestible starch are fed to broilers, a frac-
tion of starch may leave the small intestine undigested. This may
cause a shift in microbial populations. In a pilot study, involving
slowly and rapidly digestible starch sources and an experimental
non-pathogenic strain of Clostridium perfringens, fewer colony
forming units of the bacterium were observed in the caecal contents
of birds that were fed a slowly digestible starch diet than in those
fed one containing rapidly digestible starch. Although further stud-
ies need to be performed in this area, it is possible that feeding diets
containing small amounts of resistant starch may be beneficial for
gut health.

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