The European Pet Food Industry

FEDIAF Scientific Advisory Board Carbohydrate Expert Review

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TABLE OF CONTENTS

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Carbohydrates in Dog and Cat Food

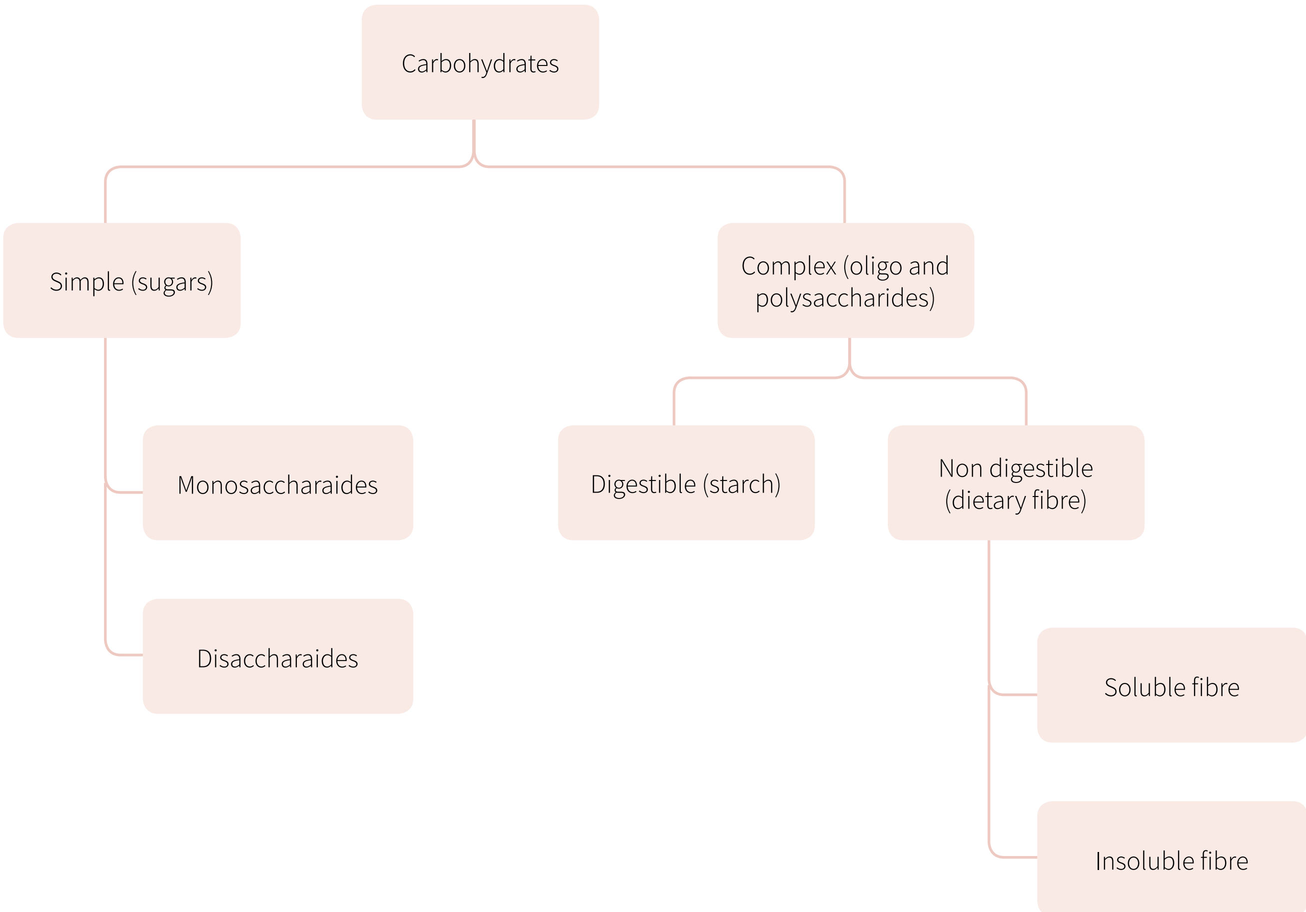
DEFINITION

Carbohydrates are one of the three categories of macro-nutrients (along with proteins and fats) in the diet of animals. They are molecules made from just three elements: carbon, hydrogen and oxygen. They are a main source of energy and provide fibre, which can be beneficial for gastrointestinal health.

The basic form of carbohydrates is the monosaccharide. Carbohydrates include mono-, di-, oligo- and polysaccharides. The way the monomers are linked (α- or β-type bonds) has important implications on their nutritional or functional roles.

STRUCTURE OF CARBOHYDRATES

The smallest and simplest forms of carbohydrates are sugars (monosaccharides and disaccharides). The larger carbohydrate molecules include oligosaccharides and polysaccharides.



Sugars

Monosaccharides

The basic and typical form of carbohydrate is that of glucose ($C_6H_{12}O_6$). Other examples of monosaccharides include fructose (also known as fruit sugar) and galactose (a component of lactose).

Disaccharides

In nature most available sugars are disaccharides, which are made of two monosaccharides that are joined together. Examples include sucrose (table sugar, one molecule of glucose linked to one of fructose), lactose (milk sugar, glucose-galactose) and maltose (glucose-glucose).

Oligosaccharides

Oligosaccharides are oligomers composed of 3 to 9 monosaccharides, often linked by β-type bounds. Examples are fructooligosaccharides, which are obtained from hydrolysis of inulin, and stachyose (fructose-$[galactose]_2$-glucose), which is one of the oligosaccharides found in many legumes.

Polysaccharides

Most polysaccharides are of plant origin but animal tissues may contain small amounts of glycogen.

Starches

Starches are long, linear (amylose) or branched (amylopectin), chains of glucose molecules linked by α-type glycosidic bonds. Starch is produced in plants for intracellular energy storage. Depending on the chain length and the degree of branching, there is a wide variety of natural starches that are stored as semi-crystalline granules. Their form also varies in size and shape between plant organs, and between plant species.

People often use incorrectly the terms 'Carbohydrates'/ 'Carbs' when they are referring to starches.

Inulin

Many plants store energy in the form of inulin rather than starch. Inulins are linear polysaccharides mainly composed of fructose molecules (up to several thousand), and typically have a terminal glucose. In inulins the fructose monomers are linked by β-type glycosidic bonds.

Gums and mucilages

Gums that readily dissolve in water and mucilages that form gels are additional groups of complex plant carbohydrate polymers.

Plant cell-wall polysaccharides

Other plant polysaccharides, often called non-starch polysaccharides, are constituents of the cell wall: celluloses, hemicelluloses, beta-glucans and pectins. While cellulose is a linear polymer of only glucose units, hemicelluloses are branched and contain many different monosaccharides. Beta-glucans comprise a group of glucose polysaccharides occurring (with hemicelluloses) in the cell walls of cereals. Lignins are also part of the cell wall, although they are phenolic polymers rather than polysaccharides. In all cell walls, the constitutive monosacharides of the polysaccharides (except pectins), are linked by β-type glycosidic bonds.

Glycogen

Glycogen is the analogue of starch as it functions as energy storage in animal tissues, mainly the liver and the muscles. Glycogen is made of glucose units and has a branched structure similar to that of amylopectin. As in starch, glucose monomers are linked by α-type glycosidic bonds.

ANALYTICAL, FUNCTIONAL AND NUTRITIONAL CLASSIFICATION OF CARBOHYDRATES

Carbohydrate analysis: chemical vs. enzymatic

In the 1860's, Henneberg and Stohmann developed the proximate analysis system for feeds.[1] They introduced a chemical-gravimetric method with weak acid and alkali digestions. It was in Weende (Germany), and the method intended to discriminate digestible (intracellular carbohydrates) and undigestible (cell wall carbohydrates) in monogastric animal feeds. The supposedly undigestible fraction was then called 'crude fibre', and the supposedly digestible one, as calculated by difference, is known as 'nitrogen-free extract', which is not a very accurate name. Moreover, it has been known for a long time that the 'crude fibre' residue underestimates (up to four times) the cell wall polysaccharide content of the foods and feeds. This inaccuracy is more likely in non-herbivore monogastrics than in herbivores. The reason for the discrepancy is that part, and unfortunately an inconsistent part, of the hemicelluloses and lignins are solubilized during the Weende analytical process.

Many improvements have been suggested over time but they never dealt with the initial limitations of the Weende method. In the 1960's, the detergent methods led to considerable improvement in the fibre content determination and thus in the prediction of the feed value. From the late 1970's, enzymatic-gravimetric methods have become the gold standard for the measurement of (total) dietary fibre (TDF). These methods are based on the action of an enzyme mix that mimics intestinal digestion by pancreatic enzymes. Moreover, they also distinguish soluble from insoluble fibre fractions.

Carbohydrate functional and nutritional classification

Carbohydrates as energy source

Glucose is the most important source of energy in animal cells, and the major one for some tissues like the brain. The body obtains glucose from sugars or polysaccharides (starch) from the diet, from endogenous stores (glycogen), or by endogenous synthesis (gluconeogenesis, especially from amino acids).

Starches are the main carbohydrate included in pet foods. Cats and dogs have intestinal (saccharase, etc.) and pancreatic (amylase) enzymes which cleave disaccharides and the α-type glycosidic bonds, respectively. Adult dogs and cats have very low lactase activity and therefore cannot properly digest lactose. Overall, dogs and cats can utilize sugars and dietary α-polysaccharides, such as glycogen and starch, provided it has been cooked. Monosaccharides are absorbed and with some differences between dogs and cats (See below 'How about cats?'), become available for energy metabolism and storage. Dietary digestible carbohydrates provide approximately 3.5 to 4 kcal metabolizable energy (ME) per gram.

In both the cat and dog salivary amylase activity is absent. Pancreatic amylase activity in the intestinal chyme of the cat is lower than in the dog.[2] Cooked starch is highly digestible in the total digestive tract of both dogs (starch digestibility ≈100 per cent)[3,4] and cats (starch digestibility ≥94 per cent with an intake ≈6g·kg of $BW^{-1}\cdot d^{-1}$).[5]

Nevertheless, the relative contributions of enzymatic digestion in the small intestine and fermentation in the hindgut may vary widely depending on the starch source and processing. Indeed, digestion and absorption can be rapidly processed, although due to structural reasons, not all starches or starch fractions are digested at the same speed. When starch is not digested, it is called 'resistant starch'. Resistant starch reaches the colon, where it can be fermented by the microbiota. For any particular food the importance of the 'resistant' fraction may vary among animal species, depending on intestinal length and transit time. Usually, cooking of starch (especially extrusion) dramatically enhances the rapidly digested fraction of starch and lowers the resistant one. This has notably been shown in cats, in which cooked maize starch was nearly fully digested. Preceacal digestibility in the small intestine was nearly 70 per cent, with around 30 per cent of the starch fermented in the colon.[6] In the same experiment, preceacal digestibility of raw maize starch was around 45%, and the overall digestibility was about 70%.[6]

N.B. If digestibility and availability only refer to what occurs in the small intestine, 'digestible carbohydrates', 'available carbohydrates' and 'glycaemic carbohydrates' are more or less equivalent terms to name carbohydrates that are sources of glucose and energy.

Dietary fibre

Non-digestible ('unavailable', 'non-glycaemic') carbohydrates are often referred to as 'dietary fibre'. This is a heterogeneous group of substances defined as polysaccharides (10 or more monomeric units) which are not hydrolysed by the endogenous enzymes in the small intestine of monogastric animals. Dietary fibre usually includes the edible carbohydrate polymers naturally occurring in food, including plant cell wall polysaccharides, lignins, inulin, gums and mucilages. Digestion-resistant oligosaccharides are also considered dietary fibre.

Dietary fibres are usually classified according to their fermentability (rapidly fermentable, slowly fermentable or non-fermentable) or their solubility (soluble vs. insoluble). These attributes are not necessarily correlated, although soluble fibres tend to be more fermentable. Other important fibre characteristics include water holding capacity, bulking and viscosity. All these characteristics modify the effects of dietary fibre in dogs and cats.

Like other monogastric animals, cats and dogs lack enzymes to break down β-glycosidic bonds. Only microorganisms produce the β-glycosidases that allow, in the colon, the hydrolysis of the β-type polysaccharides. This is the first step of a fermentative process, which is the way the microorganisms obtain energy from available substrates. Short chain fatty acids are among the fermentation end-products. These can be absorbed in the colon and provide some energy to the dog or cat, but with a relatively low efficiency compared to glucose. Colonic fermentation is a slower process than small intestine digestion and, therefore, not all potentially fermentable substrates are completely fermented due to the relatively short residence time in the colon. Fermented carbohydrates (either β-type polysaccharides, oligosaccharides or resistant starch) provide between 1 and 2 kcal/g (kcal ME)[7]; this is considered negligible in dogs and cats.

Depending on its solubility and fermentability, dietary fibre can have health benefits for dogs and cats related to intestinal health and satiety. Soluble fibres, which dissolve in water, can in some cases increase viscosity in the gastrointestinal tract. This would delay gastric emptying and modify the postprandial glycaemic response. Some sources can be fermented in the colon, which results in increasing production of short chain fatty acids. Some oligosaccharides in the soluble fibre have prebiotic effects as they specifically induce growth and activity of beneficial microorganisms (such as *Bifidobacteria*).

Insoluble fibres, which do not dissolve in water, can be metabolically inert, although a small fraction may be slowly fermented in the large intestine. Their low density and high porosity combined with their water holding capacity result in higher faecal bulk. This can result in easier defecation and improved faecal consistency. Insoluble fibre is not usually a source of energy for cats and dogs and, therefore does not contribute to weight gain. That is why it is used in specially formulated weight management diets to provide bulk and potentially improve satiety.

Sources of carbohydrates

The main sources of starch are cereals and also root vegetables and legumes. These ingredients also provide fibre. Soluble fibre can be found in different quantities in cereals, fruits and vegetables, while insoluble fibre can be found in high concentration in whole grains and fruit skin. Fibre can also be provided by purified fibre sources like cellulose or psyllium husk.

Labelling of carbohydrates in pet food

According to the EU law the following nutrients (provided as percentages, i.e. grams of nutrient per 100 grams of food) must be declared under Analytical Constituents of cat and dog food:

- Protein (or Crude protein)
- Fat content (or Crude oils and fats)
- Crude fibre
- Crude ash (or Incinerated residue, or Inorganic matter)
- Moisture content (not mandatory for dry foods; if not listed on standard pet food the moisture content is below 14%)

There is no measure of digestible carbohydrates (sugars and starch) reported on the label. In order to obtain an estimation of digestible carbohydrates in pet food (mainly starch), it can be calculated by difference. This estimation is called 'nitrogen-free extract' (NFE).

- % NFE = 100 - (Crude protein + Crude fat + Crude fibre + Ash + Moisture)

Crude fibre analysis largely underestimates the actual content of dietary fibre and does not provide any information regarding physicochemical or biological properties. As a consequence, NFE usually overestimates the content of digestible carbohydrates.

Therefore 'crude fibre' does not provide accurate information concerning the functional and nutritional properties of carbohydrates. Since pet foods usually contain only very few (if any) sugars, it would be preferable to determine the starch content, which is easy to do, and calculate the dietary fibre content (non-starch polysaccharides) by difference.

It is also possible to determine the dietary fibre content and calculate starch by difference. Nevertheless, the reported fibre content can vary depending on the definition and/or the method used to quantify it.[8]

Can dogs digest cooked starch?

Despite the perception held by some that dogs should eat the same food as wolves, studies have shown that dog can digest cooked starch. A genome study of dogs and wolves showed that dogs have higher number of copies of genes enabling them to digest cooked starch.[9] The study looked into genomes of 14 different breeds of dogs and compared them to genomes of wolves and indicated that dogs have an increased ability to digest starches and break them down into sugars as available source of energy. This evolutionary change has occurred in the past 10,000 years of humans farming crops and domesticating dogs, resulting in both humans[10] and dogs being able to increase starch consumption. Nevertheless, differences have been shown among dogs regarding their responsiveness to resistant starch (which had been determined in vitro, by 'resistance' to digestion by pancreatic α-amylase and amyloglucosidase).[11] This could reflect differences in the ability to digest carbohydrates that could result from differences in the evolutionary process due to differences in dietary pressure. Indeed it has been shown that the number of copies of the gene coding for pancreatic amylase is less in Arctic and Australian dogs, which evolved in areas where agriculture developed later.[12] Nearly 70 per cent of the variation in the gene copy number would depend only the breed, the remaining depends on individuals. Indeed, within one breed it could vary between 2 and 10, and in another one between 12 and 21.[12,13]

How about cats?

Cats are strict carnivores and, in their natural habitat, as solitary hunters, they consume small prey. They have evolved on a diet that is high in protein, with moderate amounts of fat and little carbohydrate.

Neither cats nor dogs have an absolute requirement for carbohydrates; they need glucose but as carnivores are able to synthesize glucose de novo, from amino acids. Cats are nevertheless able to utilize carbohydrates as an energy source, as long as the carbohydrates are properly processed.[5] They have pancreatic amylase and, even if the activity of amylase is rather moderate compared to other species, cats can accommodate diets with varying amounts of carbohydrates, including starch, with a reported apparent total tract digestibility between 94 per cent and 100 per cent[5,14] in diets containing 35% of starch ingredients. Cats are carnivorous, and their natural diet is mainly composed of protein and fat as energy sources. Endogenous de novo glucose synthesis (gluconeogenesis) from amino acids is very active. The activities of rate-limiting enzymes of gluconeogenesis are higher in cats than in dogs.[15] Cats lack hepatic glucokinase, the enzyme which is responsible for glucose uptake in case of increased blood glucose. Nevertheless, cats can use glucose as they have hexokinase.

While cats, similarly to dogs, do not have a requirement for starch and carbohydrates they are able to utilize them as an energy source as long as they are adequately processed and present in moderate amounts.

It has been suggested that high dietary carbohydrate levels could alter energy metabolism and reduce insulin sensitivity[16] but this has not been confirmed. Many studies have been conducted regarding the impact of dietary carbohydrates on biomarkers for disease risk and they have not found a clear association of carbohydrate intake with diabetes mellitus risk in cats. Diet can increase the risk of this disease mainly due to its association with obesity rather than to its nutritional composition.[17,18]

Epidemiological studies found that dry foods (which likely contain more carbohydrates than wet ones, and also can have increased energy density) do not affect diabetes risk[19], or are associated with a reduced risk[20]; however, one study found that dry diets were associated with a higher risk of diabetes in lean but not fat cats.[21] This would warrant further research, especially regarding the specific effect of the carbohydrate content which greatly varies in dry foods (from 10% to more than 40% of the energy, i.e. from 20 to 50% of dry matter). The amount and/or the ingredient source may affect metabolic responses.[22]

Based on currently published evidence, it appears that a sedentary lifestyle, living indoors, neutering, and consuming foods that are high in fat and energy have all been identified as risk factors for obesity rather than the carbohydrate content of the diet.

What about low-starch diets?

Starch is overall higher in dry diets compared to moist diets, due to its importance in the extrusion process. However, some moist foods can have starch contents comparable to dry foods. Why is it included, if it is not an essential nutrient? The main reason is that starch is an available source of energy; it may typically represent 40-50% of energy in dog dry diets, and 15-40% in those for cats.

Reducing the starch diets content requires increasing dietary protein or fat (or both) to provide energy. High-protein and/or high-fat diets can be complete and balanced. They may be well tolerated in some pets, but their generalized use as maintenance diets for healthy animals is questionable. Indeed, high-fat diets are known to predispose to overweight, at least in neutered animals, as it has been shown in cats.[23,24] High fat diets also induce a lower degree of satiety. The use of high protein diets has ethical, economic and environmental concerns, considering that especially animal protein is a scarce resource and high protein intake results in increased nitrogen excretion.

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