Journal of Animal and Feed Sciences, 13, 2004, 523–538

Nutritional and health functions of carbohydrate for pigs*

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(Received 6 December 2003; revised version 31 May 2004; accepted 25 October 2004)

ABSTRACT

The greatest progress in carbohydrate study in pig nutrition and health is that the carbohydrates are classified more clearly not only based on their structure, but also on their nutritional functions. Carbohydrates serve as components of cell structures, energy substrate and have regulatory functions. There are large differences in the digestion, absorption and the speed of the carbohydrates appearance in the portal vein blood plasma. Non-starch polysaccharides (NSP) and particularly soluble one and resistant starch (RS) may have negative effects on dietary nutrient utilization in pig growth, however, some of the NSP and RS have health benefits.

KEY WORDS: carbohydrate, pig, nutrition, health

THE SIGNIFICANCE OF CARBOHYDRATE

Carbohydrates are important in the nutrition of pigs because they are the primary source of energy that provides at least 50% of the total cost of

* Supported by National Basic Research Program of China (2004CB117502), (NSFC 30371038), K.C. Wong Education Foundation Hong Kong and CAS (KSCX2-SW-232)

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pork production and because they affect digestion and the function of the gastrointestinal tract of pigs and humans. Since carbohydrates represent such a major part of the diet, characterizing their functions and improving their utilization are very important.

For growing pigs, up to about 50 kg body weight, feed intake capacity limits the expression of growth potency. Gut capacity of the pig from 20 to 50 kg liveweight is 1.8 to 2.0 kg/d, consequently it requires 12.1 to 14.4 MJ/kg metabolizable energy (ME) in the diet in order to achieve the optimum ME intake of 28.8 to 30.7 MJ/d for fast growing pigs (Campbell, 1990; Campbell et al., 1990). Furthermore, it has been suggested that fast growing pigs will experience rate of protein deposition (PDR) reduction of the order of 6 g for every 1 MJ reduction in DE intake below the optimum (Rao and McCracken, 1991). This indicates that pig growth especially for the starter requires high digestible carbohydrate supply.

It has been found that many natural oligosaccharides can affect biological functions of animal (Spring and Privulescu,1998; Patterson and Burkholder, 2003). These developments let us re-recognize the importance of carbohydrates in life sciences. Moreover, as the advances of the studies of separation and structure analyses of carbohydrates, a new discipline has been emerged as "glycobiology" in recent years (Zhou, 1999). A "European Carbohydrate Platform" was initiated during 1994-1998 Research Program of European Commission. A "Glycobiology and Oligosaccharides Engineering Center" was created in the Chinese Academy of Sciences in 2001.

Oligosaccharides are produced in commercial quantities either by extraction from plant and bacterial sources, or more commonly by synthesis under the control of transglycosidase. The activity of these compounds as we understand them today is twofold: adsorption of enteric pathogens and immunomodulation (Spring and Privulescu, 1998). Oligosaccharides have widely used as additives in human, animal and plant. The world total oligosaccharide production was up to 130 thousand tones in 1998. Resistant starch (RS) and non-starch polysaccharides (NSP) can be also exploited for the development of functional foods for humans. Resistant starch and NSP can decrease dietary caloric value, which is important in the prevention of obesity. In addition RS and NSP can also reduce the risk of colonic cancer through increasing short-chain fatty acid production, especially butyrate.

CLASSIFICATION OF CARBOHYDRATES

Carbohydrates may be classified according to degree of polymerization; identity of constituent sugars and type of glycosidic linkages present. Table 1 shows this method of classification for food carbohydrates (Englyst and Hudson, 1996), as well as their likely fate in the small intestine.

TABLE 1

Classification of food carbohydrates (Englyst and Hudson, 1996)

Type	Constituent sugar	Hydrolysed and absorbed in the small intestine	Included in analysed NSP fraction	
			Englyst NSP	AOAC residue
Sugars	glucose, fructose, sucrose, lactose	Mostly	No	No
Sugar alcohols	sorbitol, xylitol, lactiol, maltitol	Sparsely	No	No
Short-chain carbohydrates (SC) (soluble in 80 ethanol)	resistant SC (fructo-and galacto-oligosaccharides, pyrodextrins, polydextrose)	No	No	No
	maltodextrins	Yes	No	No
Oligosaccharides < 10 monomers	α-galactosides (raffinose, stachyose and verbascose)	No	No	No
Starch	rapidly digestible starch	Yes	No	No
	slowly digestible starch	Yes	No	No
	resistant starch	No	No	Partly
Non-starch polysaccharides	present as plant cell-walls (dietary fibre)	No	Yes	Yes
	other NSP (gums, pectin, mucilages, any isolated NSP)	No	Yes	Yes

The sugars are mostly absorbed in the small intestine. The major source of sugar alcohols in the diet is as additives and they are not well absorbed, and some that are absorbed are excreted in urine.

Short-chain carbohydrates are a new category in the classification of food carbohydrates. The current system of separating non-monomer carbohydrates into oligosaccharides and polysaccharides with a dividing point at about 10 monomer residues. In practice, the polysaccharides have been traditionally identified as the carbohydrate insoluble in 80% ethanol. Starch, a mixture of the α-glucan polysaccharides amylose and amylopectin in proportions that depend on the botanical origin, represents 80-90% of all polysaccharides in the pig and human diets. These plant storage polysaccharides contain only α-glucosidic linkages and are, therefore, potentially digestible by the amylolytic enzymes secreted by pig and human digestive tract. However, certain factors can influence the rate at which starch is hydrolysed and absorbed. It is therefore convenient to consider subdividing this class for nutritional purposes. Table 2

TABLE 2

In vitro nutritional classification of starch (Englyst et al., 1992)

Type of starch	Example of occurrence	Probable digestion in small intestine
Rapidly digestible starch	Freshly cooked starch food	Rapid
Slowly digestible starch	Most raw cereals	Slow but complete
Resistant starch		
physically inaccessible starch	Partly milled grains and seeds	Resistant
resistant starch granules	Raw potato and banana	Resistant
retrograded starch	Cooled cooked potato, bread and corn flakes	Resistant

lists rapidly digestible starch, slowly digestible starch and resistant starch fractions. The rate and extent of the digestion of starch is reflected in the magnitude and the duration of the glycaemic response.

In vitro study shows that starch digestion is more slowly than simple sugar or disaccharides and its physical form is the major effect of digestion and absorption. The various types of starch are determined by controlled enzymatic hydrolysis and measurement of the released glucose using glucose oxidase according to the *in vitro* method of Englyst et al. (1992). Total starch is determined as the glucose released by enzymatic hydrolysis following gelatinization in boiling water and treatment with potassium hydroxide to disperse retrograded almost. Total starch is corrected for free glucose but includes maltose and maltodextrins. Rapidly digestible starch and slowly digestible starch are measured after incubation with pancreatic amylase and amyloglucosidase at 37°C for 20 min and a further 100 min. Resistant starch is the starch not hydrolysed after 120 min incubation. Starch digestion index is calculated as: Starch digestion index = rapidly digestible starch/total starch ×100.

Rapidly available glucose (RAG): during the measurement of rapidly digestible starch and slowly digestible starch, a value is obtained for RAG as the glucose measured after 20 min incubation with the enzymes. Rapidly available glucose = free glucose + glucose from sucrose + glucose released from starch with 20 min incubation. Various types of starch and its ileal digestibility in some carbohydrate ingredients are listed in Tables 3 and 4.

The NSP comprise 700-900 g/kg of the plant cell wall, with the remaining being lignin, protein, fatty acids, waxes, etc. (Bach Knudsen, 2001). Plant cell wall NSP is a diverse group of molecules with varying degrees of water solubility, size and structure, which may influence the rheological properties of the gastrointestinal

TABLE 3

In vitro digestibility (g/100 g DM) of some carbohydrate-containing ingredients (Englyst et al., 1992)

Sample	Rapidly digestible starch	Slowly digestible starch	Resistant starch	Total starch	Starch digestion index	Rapidly available glucose
Wheat flour	40	39	2	81	49	40
Maize	73	2	3	78	94	81
Oats	57	6	2	65	88	49
White rice	60	12	6	78	93	81
Cooked rice	78	1	<1	79	98	86
Potato starch (raw)	6	19	75	99	6	5
Banana flour	3	15	57	75	4	6
Faba bean	27	16	6	49	55	8
Peas	12	2	5	20	60	9
Glucose	100			100	100	100

TABLE 4

Total and resistant starch (RS) composition (%) and ileal digestibility (%) of starch of sorghum (SG), pear millet (PM), high oil maize (HOM), high oil high protein maize (HOPM), normal maize I (CI) and normal maize II fed to growing pigs (CII) (Yin et al., 2002)

Ingredients	Total starch %	Resistant starch 0.5 h	Resistant starch 3 h	Resistant starch 16 h	Digestibility %
Sorghum	58	34	8	0.2	96.5
Millet	52	32	3	0.2	97.8
HOM	50	31	4	0.1	98.6
HOPM	44	23	2	1.3	98.4
CI	66	39	6	1.7	98.1
CII	62	39	7	0.1	98.5

contents, flow of digesta and the digestion and absorption process to a variable degree. The action of NSP in the stomach and small intestine is essentially a physical one, in which the plant cell either acts as barrier to the release of nutrients or increases the viscosity of the liquid phase and restricts their absorption. The effect of NSP on the digestion and absorption in the small intestine is more difficult to predict from any of the chemical parameters currently measured.

Over 100 monosacharides are found in nature but only about nine of these are the predominant building blocks of NSP (Albersheim et al., 1984; Henry, 1985). These include the pentoses (arabinose and xylose), the hexoses (glucose, mannose and galactose), the 6-deoxyhexoses (rhamnose and fucose) and the hexauronic acids (galacturonic acid, glucuronic acid). These sugars are joined by glycosidic bonds between the hemiacetal group of one sugar and the hydroxyl group of another. The bonds are identified by the carbon atoms of each sugar that are involved in the bond (1 to 6 for hexoses and 1 to 5 for pentoses) and the orientation of the oxygen atom in the hemiacetal group (primarily β). The number of potential polysaccharide structures is enormous (Albersheim et al., 1984).

The main NSP composition in cereal grain are list in Table 5. The results show that arabinose and xylose are the major NSP compounds in wheat and rice seed endosperm, while content of glucan in barley is higher than that in wheat and rice seed.

Most ingested vegetable materials have a high water-holding capacity with most water retained within the lumen in the pig, begins to macerate the tissue reducing the mean particle size until, when reaching the hindgut, some 90% of dry matter has been fermented and virtually all structure and thus water-holding and bulking capacity has disappeared. Lignified cell walls, in contrast, although losing some 40% of dry matter due to microbial action, tend to retain their cellular integrity and their bulking capacity throughout the digestive tract as shown in Table 6. This difference in the extent to which physical structure is retained in reflected in significant effects on gut motility and transit time.

TABLE 5

Detailed sugar composition of non-starch polysaccharides (%) for a range of cereal grain

Sample		Total NSP	Rhamnose	Fucose	Arabinose	Xylose	Mannose	Galactose	Glucose	Uronic acids
Wheat[1]	Sol[1]	1.4	0.03	0.02	0.33	0.17	0.03	0.35	0.17	0.25
	Ins[2]	12.6	0.04	0.04	3.62	5.25	0.17	0.38	2.56	0.55
	Total	14.0								
Barley[1]	Sol	1.4	0.019	0.02	0.24	0.12	0.029	0.22	0.59	0.18
	Ins	12.3	0.03	0.03	2.96	4.8	0.21	0.27	3.68	0.35
	Total	13.7								
Wheat bran[1]	Sol	3.2	0.076	0.068	0.64	0.47	0.1	0.74	0.6	0.5
	Ins	68.9	0.18	0.98	17.3	32.2	0.51	1.42	14.3	2.01
	Total	72.1								
Rice bran[3]	Sol	3.0	0.07	0.05	0.52	0.41	0.1	0.64	0.50	0.41
	Ins	74.1	0.20	1.0	19.5	35.2	0.61	1.00	14.6	2.03
	Total	77.1								
Oats-hulled[4]	Sol	4.0								
	Ins	11.0								
	Total	15.0								
Oats-hulless[4]	Sol	5.4								
	Ins	4.9								
	Total	10.3								
Oat hull meal[4]	Sol	1.3								
	Ins	29.5								
	Total	30.8								
Sugar beet pulp[4]	Sol	40.7								
	Ins	17.7								
	Total	58.4								

[1] soluble

[2] insoluble

[3] Yin et al., 2000a,b,c; 2001a,b

[4] Bach Knudsen, 2001

CARBOHYDRATE DIGESTION AND ABSORPTION

Non-starch polysaccharides (NSP) or acid detergent fibre (ADF) and neutral detergent fibre (NDF) digestibility at the terminal ileum

The ileal digestibility of NSP, ADF and NDF varied between experiments. The ileal digestibility of NSP, ADF and NDF at this site of the gastrointestinal

TABLE 6

Comparison of the effects of fibre from a readily fermentable vegetable source (Rutabaga) and a less fermentable cereal source (wheat bran) on the digestive physiology of a growing (70 kg) pig (Chesson, 1998)

Parameter	Wheat bran	Rutabaga
Total fibre in diet, g/kg DM	250	250
Soluble fibre, g/kg DM	22.9	71.2
Lignin, g/kg DM	19.8	2.9
Water-holding capacity, g H_2O/g DM	2.9	32.1
Overall digestibility, %	41.5	87.8
Ileal digestibility, %	4.6	45.2
Particle size in diet, µm	1197	2398
Particle size in faeces, µm	907	228
Transit time, h	36	58
Total VFA-terminal ileum, mmol/kg DM	124	191
Total VFA-caecum, mmol/kg DM	1180	3035
Total anaerobes-terminal ileum, $\log_{10}$cfu/g DM	10.5	8.2
Total anaerobes-caecum, $\log_{10}$cfu/g DM	10.4	11.2

tract is influenced by the type of dietary fibre, but factors of feeding levels and sampling techniques, etc. are probably also involved in. The ileal digestibility of NSP, ADF and NDF in some cereal and legume diets are presented in Table 7.

TABLE 7

Ileal digestibility (%) of non-starch polysaccharides (NSP), acid detergent fibre (ADF) and neutral detergent fibre (NDF) in some feedstuff fed to growing pigs (Yin et al., 1993, 1994, 2000, 2001; Bach Knudsen, 2001)

Diet	NSP	ADF	NDF
Rice seed		23	38
Peanut meal		32	41
Rapeseed meal		37	46
Cottonseed meal		40	44
Soyabean		38	46
Peas		31	52
Wheat bran	15	38	58
Maize		39	62
Jack bean		25	64
Mung bean		15	66
Hulless barley	20		
Wheat middling	30		
Oat bran	36		
Sugar beet pulp	37		
Peas	40		

Sugar and starch absorption

As the supply of energy-yielding nutrients at the sites of protein synthesis should be synchronized with the supply of amino acids to make the synthetic process optimal, variation in the nutritive value of sugars might be due to a different chronology in the digestion and absorption of their hydrolysis products, as well as to the different nature of the later. Until now, most of the estimation of the amounts of nutrient available for the pig during digestion was made by the means of the digestibility studies, but only few studies were conducted to quantify the precise kinetics of their appearance in the organism and their transformation during transit and absorption. Rerat et al. (1984) and Yen et al. (1987) have developed the method for chronically quantifying net absorption of nutrients and gut metabolites into hepatic portal vein in conscious pigs, however, the surgery technique is complex and time-consuming. Recently, we have made some development on the techniques for cannulating the portal vein blood vessels described by Rerat et al. (1980) and Yen et al. (1987) and made the technique easy to use (Huang et al., 2003).

Rerat et al. (1984), studied the digestion and absorption of four different types of carbohydrates (glucose, sucrose, lactose and maize starch) in conscious pigs with a technique based on the determination of blood flow-rate in the portal vein combined with the measurement of the portal-arterial differences of nutrients. They suggested: 1. the supply of energy is not chronologically the same when another replaces one sugar even for an unchanged dietary energy content (Table 8), 2. what influence, however, do such variations have on the utilization of carbohydrates and proteins by the tissues?, 3. the slow digestion of some carbohydrates, such as lactose, may favour the arrival of fermentable substrates in the large intestine leading to formation of either useful or noxious substances. We have also studied the net glucose absorption in portal vein when pigs were fed two different carbohydrate diets: a maize starch based diet and the starch based diet being replaced by 8% of pectin (soluble NSP). The results are shown in Table 8.

TABLE 8

Amounts (g) of glucose appearing in the portal blood during a post-prandial period of 8 h after intake of different carbohydrates (Rerat et al., 1984 and Yin et al., 2002, unpublished[1])

Carbohydrates intake, g	Carbohydrate	Cumulative amount of glucose appearing in the portal vein, g			
		2 h	4 h	6 h	8 h
400	Glucose	65.2	156.3	195.4	207.5
400	Sucrose	48.4	96.2	123.6	137.0
400	Lactose	25.7	50.5	67.2	77.4
400	Maize starch	61.7	110.7	148.0	183.2
800	Glucose	133.2	304.6	413.9	509.7
800	Sucrose	69.2	162.1	237.1	283.5
800	Lactose	20.5	39.6	57.4	73.5
800	Maize starch	88.7	185.9	254.0	309.0
337[1]	Maize starch	52.5	91.3	123.9	131.2 (7h)
293[1]	Maize starch + 8% pectin	39.9	67.2	93.7	99.0 (7h)

EFFECTS OF NON-STARCH POLYSACCHARIDES (NSP) ON PIG NUTRIENT UTILIZATION AND GASTROINTESTINAL BACTERIAL FERMENTATION

Non-starch polysaccharides (NSP) and particularly soluble ones, which have antinutritional properties by changing the function of the gastrointestinal tract. Soluble NSP encapsulate nutrients and thus depress overall nutrient digestibility and increase endogenous nitrogen flow and bacterial fermentation in the gastrointestinal tract. Yin et al. (2000a) reported that NSP stimulate endogenous N flow (Table 9) and hindgut fermentation (Table 10). The results of Table 10

TABLE 9

Effect of wheat non-starch polysaccharides (NSP) on dry matter (DM) and nitrogen (N) flows at the terminal ileum (Yin et al., 2000a)

Indices	Wheat	Wheat middling	Wheat bran	SEM
Dietary NSP level, g/kg DM	87	150	190	
DM/g/kg DM intake	236.9^{c}	375.9^{b}	413.1^{a}	10.42
Total N, g/kg DM intake	6.7^{b}	9.47^{a}	9.37^{a}	0.444
Endogenous N, g/kg DM intake	4.14^{b}	6.42^{a}	5.98^{a}	0.527

^{a,b,c} values in the same row with different superscript letters differ at $P<0.05$

TABLE 10

Effects of dietary non-starch polysaccharides (NSP) level and enzyme cocktail supplementation on apparent ileal and overall digestibility and hindgut fermentation (HF) (%) of dry matter, gross energy, crude protein, neutral detergent fibre (NDF) and NSP of pigs fed Phoenix, Falcon, Silky, Buck and Condor based diets [1] (Yin et al., 2001b)

	Diet					Enzyme	
	Phoenix	Falcon	Silky	Condor	Back	-	+
Dietary NSP level, g/kg DM	138.2	140.0	145.8	153.9	154.8		
Ileal digestibility							
dry matter	63.4^{a}	61.4^{ab}	60.0^{bc}	60.6^{bc}	58.3^{c}	58.4^{b}	63.1^{a}
gross energy	64.3^{a}	62.3^{ab}	60.6^{bc}	61.9^{bc}	59.0^{c}	59.0^{b}	64.4^{a}
crude protein	70.6^{a}	67.4^{ab}	66.1^{b}	57.1^{c}	57.3^{c}	62.1^{b}	66.4^{a}
NDF	17.2	17.5	17.5	18.8	15.9	13.0^{b}	20.0^{a}
NSP	29.3	30.1	31.6	27.8	31.7	25.5^{b}	33.6^{a}
Overall digestibility							
dry matter	80.6^{a}	77.2^{ab}	76.2^{b}	78.6^{ab}	75.7^{b}	76.6^{b}	79.0^{a}
gross energy	79.9^{a}	76.0^{b}	75.4^{b}	76.6^{b}	76.5^{b}	75.3^{b}	78.9^{a}
crude protein	74.7^{a}	71.8^{b}	71.2^{b}	72.4^{b}	72.3^{b}	71.4	73.4
NDF	51.6	52.0	56.4	54.8	52.2	50.4^{b}	56.5^{a}
HF digestibility							
dry matter	47.0	45.1	41.5	41.1	40.3	45.0^{a}	41.6^{b}
gross energy	43.7	39.8	37.6	40.1	38.3	41.2^{a}	37.3^{b}
crude protein	13.9^{b}	13.5^{b}	15.0^{b}	20.2^{a}	23.0^{a}	9.9^{a}	7.3^{b}
NDF	41.5	40.0	37.8	38.9	43.2	40.0^{a}	31.1^{b}

[f] fermentation expressed as a proportion of undigested material reaching hindgut (=fermentation expressed as the difference between overall and ileal digestibility/100 - ileal digestibility)

^{a,b,c} values in the same row with different superscript letters differ ($P<0.05$)

show that more than 70% of dietary gross energy and 85% of crude protein in the test barley is digested in the small intestine. A significantly higher hindgut fermentation of crude protein for the higher NSP diets of condor and buck than others indicated that the extent of microflora digestion of dietary protein in the hindgut depends on the amount of fermentable carbohydrate and protein reaching the large intestine. Since the ileal digestibility of dry matter, energy and protein in the diets of condor and buck were significantly lower than others; these two varieties of barley may provide a high amount of fermentable carbohydrate and protein in the large intestine, which potentially could enhance the growth of microflora. However, fermentation of undigested dietary protein residues by microflora in the large intestine yield products of no nutritional value to the pig (Żebrowska, 1973) and the net energy value utilized from the small intestine is 30% higher than that from the large intestine (Dierick et al., 1989). Bach Knudsen (2001) summarized the effects of soluble, insoluble and total dietary fibre on rheological properties of the gastrointestinal content and digestion and absorption processes in pigs (Table 11). Undigested soluble NSP may exacerbate such diseases as dysentery. Hence, controlling hindgut microbial activity, particularly through nutritional means, may be of increasing relevance as the use of feed antibiotics is more and more constrained.

TABLE 11

Summary of effects of soluble, insoluble and total dietary fibre on rheological properties of the gastrointestinal content and digestion and absorption processes in pigs (Bach Knudsen, 2001)[1]

Indices	Dietary fibre		
	soluble	insoluble	total
Stomach			
viscosity	***	*	**
WBC[2]	**	***	**
emptying	*(*)	*	*
Small intestine			
viscosity	**	-	*
WBC	**	***	***
glucose absorption	(*)	-	-
Large intestine			
fermentation	****	***	***
bulking	*	****	****
MTT[3]	-	***	***
Energy			
ileum	***	****	****
faeces	-	****	****

[1] * - no relation; - ****: relative strengths of relation

[2] water binding capacity

[3] mean tansit time

Some disease conditions, such as swine dysentery and acidosis in ruminants and horses, have great economic significance and are closely related to the status of the gut microfloral fermentation. For an example, pig dysentery is caused by a spirochaete bacterium that resides in the large intestine, and the proliferation of this bacterium is inhibited by low rates of fermentation, as indicated by Pluske et al. (1996, 1998). They showed that diets based on cooked rice and animal proteins can give a high level of protection against pig dysentery. Steam-flaking of maize and sorghum can also eliminate or largely reduce the incidence of pig dysentery, but this type of processing is ineffective for wheat, barley, or groats. The increased fermentation in the large intestine may be due to an elevated level of NSP in the diet. In the case of maize and sorghum, steam-flaking may have disrupted the cell wall matrix, making the starch granules more susceptible to amylase, thereby speeding up starch digestion in the upper part of the gut (Figure 1, Table 12).

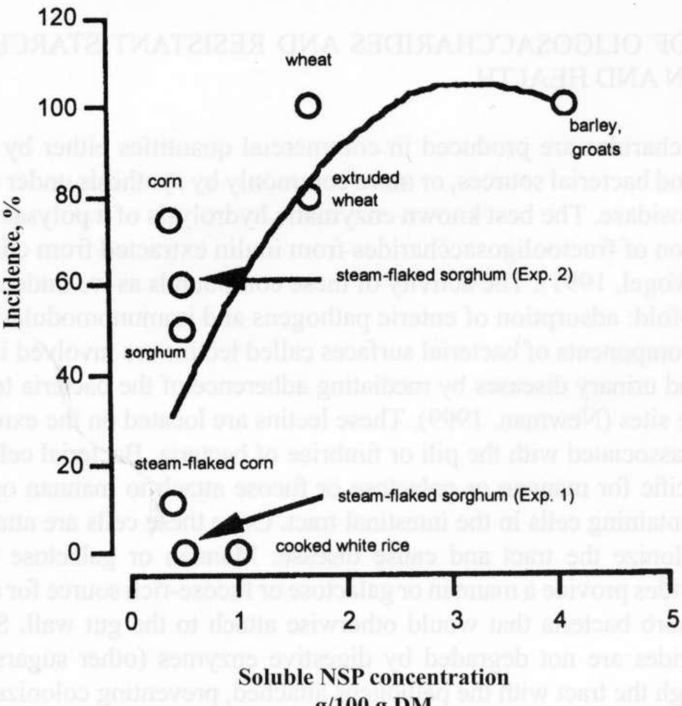

Figure 1. The relationship between the incidence of pig dysentery (%) and soluble non-starch polysaccharides (NSP) concentration of diets (g/100g DM) ($y=9.52 + 56.98x - 8.47x^2$; $R^2=0.561$) (Pluske et al., 1996)

TABLE 12
Development of pig dysentery in animals infected with *Serpulina hydosenteriae* and fed rice-based diets containing different sources of carbohydrate or an animal protein-soyabean meal supplement or increasing levels of resistant starch (RS) (Pluske, 1998)

	Diet							
	rice-guar gum	rice-RS	rice-oat chaff	rice-guar gun+RS	rice-animal protein	rice-RS		
						13.2%	20%	27%
S. hydosenteriae isolated from rectal swabs	5	5	1	5	0	5	5	5
Incidence of SD	4	0	0	5	0	5	4	3
Faecal shedding	19	11	1	17	0	12	14	16
Post-morten gross lesions	4	0	0	5	0	5	4	4
S. hydosenteriae isolated from lesions	4	0	0	5	0	5	4	5

EFFECTS OF OLIGOSACCHARIDES AND RESISTANT STARCH ON PIG NUTRITION AND HEALTH

Oligosaccharides are produced in commercial quantities either by extraction from plant and bacterial sources, or more commonly by synthesis under the control of transglycosidase. The best known enzymatic hydrolysis of a polysaccharides is the production of fructooligosaccharides from inulin extracted from chicory roots (Heinz and Vogel, 1991). The activity of these compounds as we understand them today is twofold: adsorption of enteric pathogens and immunomodulation.

Certain components of bacterial surfaces called lectins are involved in the onset of enteric and urinary diseases by mediating adherence of the bacteria to epithelial cells in these sites (Newman, 1999). These lectins are located on the exterior of the cell and are associated with the pili or fimbriae of bacteria. Bacterial cells with pili that are specific for mannan or galactose or fucose attach to mannan or galactose or fucose-containing cells in the intestinal tract. Once these cells are attached, they can then colonize the tract and cause disease. Mannan or galactose or fucose-oligosaccharides provide a mannan or galactose or fucose-rich source for attachment that will adsorb bacteria that would otherwise attach to the gut wall. Since these oligosaccharides are not degraded by digestive enzymes (other sugars do), they passes through the tract with the pathogens attached, preventing colonization.

Act as a carbon source for specific "beneficial" strains of gut bacteria encouraging their numbers to increase the proportion of the total flora (Chesson and Austin, 1998).

Several studies have been conducted in examining the role of oligosaccharides on binding of pathogens to epithelial cells in GIT. Nemcova et al. (1999) determined the effect of feeding oligofructose and *Lactobacillus paracasei* on the microbiota of pigs weaned at 36 days of age. Feeding the symbiotic combination resulted in higher numbers of total anaerobes, total aerobes and *Lactobacilli*. They observed a decrease in enterobacteria and clostridia. Farnworth et al. (1992) fed weanling pigs with oligofructose and found there were numerical increases in total anaerobes, total aerobes, *bifidobacteria* and *coliforms*.

A number of trials have shown trends for improvements in growth performance, decrease in variation, mortality and morbidity associated with feeding prebiotics to pigs. Estrada et al. (2001) fed early weaned pigs oligofructose for 21 days with two inoculations of *Bifidobacterium longum* in the first week. There was a numerical increase in gain and a significant improvement of feed efficiency in pigs fed the symbiotic combination. Orban et al. (1997) observed numerical increases in performance of weaned pigs fed oligofructose or an antibiotic in 2 trials. Antibiotic response was numerically higher than oligofructose response in these studies.

Now many scientists consider resistant starch (RS) has the same functions as oligosaccharides. Pig caecal and colonic bacteria ferment RS to short-chain fatty acids (SCFA), maily acetate, propionate and butyrate. Short-chain fatty acids stimulate caecal and colonic blood flow and fluid and electrolyte uptake. Butyrate is a preferred substrate for colonocytes and appears to promote a normal phenotype in these cells (Topping and Clifton, 2001). Topping et al. (1993) reported that pH values are lower in pigs fed diets that raise large bowel SCFA. Lower pH values are believed to prevent the overgrowth of pH-sensitive pathogenic bacteria (Cherrington et al., 1991). Kleessen et al. (1997) reported that RS stimulate large intestinal *Lactobacilli* production on rats, although the *Enterobacteria* were stimulated by retrograded starch (Table 13).

TABLE 13

Effects of 10% raw (RS 1) and 10% retrograded potato starch (RS 2) in the diet on caecal bacterial counts after a 5-month experimental period (Kleessen et al., 1997)

Treatment	Total	*Fusobacteria*	*Bifidobacteria*	*Clostridia*	*Lactobacilli*	*Streptococci*	*Enterobacteria*
Control	10.0	9.8	6.6^{c}	6.8	8.9^{d}	6.6^{d}	5.4^{d}
RS 1	9.9	9.2	9.0^{d}	6.9	8.7^{d}	7.0^{d}	5.3^{d}
RS 2	10.5	9.7	8.9^{d}	6.5	10.3^{e}	9.3^{e}	8.2^{e}
SEM	0.2	0.3	0.3	0.5	0.2	0.2	0.4

^{d,e} values in the same column with different superscript letters differ ($P<0.05$)

CONCLUSIONS

Carbohydrate is an important component in pig rations that not only provide the majority of energy for pigs, but also comprise some components which limit feed intake, digestibility and absorption, and affects pig performance. The importance of gluco- or glyconization in the life cell indicates that carbohydrate has important biological function. Due to complex structure of the carbohydrate, its effects on nutrients digestion, absorption and the gastrointestinal tract bacterial production are still not very clear and further investigation is needed. In the view of practice, it is very important to develop economic techniques for producing the rapidly digestible and resistant starch from maize and rice for providing a highly digestible carbohydrate ingredient for young pigs and prebiotics as an alternative to antibiotics.

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STRESZCZENIE

Żywieniowe i zdrowotne działanie węglowodanów u świń

Największy postęp w badaniach nad węglowodanami w żywieniu świń oraz ich znaczenie dla zdrowia polega na tym, że są one bardziej wyraźnie klasyfikowane nie na podstawie ich struktury, lecz także oddziaływania żywieniowego.

Węglowodany stanowią składnik struktur komórki, są źródłem energii oraz spełniają funkcje regulujące. Występują duże różnice w trawieniu, wchłanianiu oraz tempie pojawiania się węglowodanów w osoczu krwi żyły wrotnej. Wielocukry nieskrobiowe (NSP), a zwłaszcza rozpuszczalne i oporne skrobie (RS), mają ujemny wpływ na wykorzystanie składników pokarmowych przez rosnące świnie, jednakże niektóre z NSP i RS mają korzystny wpływ na zdrowie.