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The influence of enzyme preparations on the nutritional value of cereals for poultry. A review

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ABSTRACT

Supplementation of cereal based diets for poultry with enzyme preparations may notably improve the performance, and reduce the viscosity of digesta and excreta. However, the overall effect depends on the content of anti-nutritive non-starch polysaccharides (NSP) in diet and the age of birds. The paper presents the content of anti-nutritive NSP in barley, wheat, triticale and rye, and discusses their effect on digestion processes in birds of different ages and benefits due to exogenous enzymes supplementation.

KEY WORDS: cereals, poultry, feed enzymes, nutritional value

INTRODUCTION

Application of enzymes to poultry feed includes providing the animal with exogenous enzymes. The aims of such measures are (modified according to Jeroch and Müller, 1992; Brufau et al., 1993a; Simon et al., 1993):

1. Degradation of antinutritive substances and a simultaneous increase in the availability of other nutrients (e.g. the partial degradation of ß-glucan by ß-glucanase is connected with improved digestibility of nutrients and an increase in metabolizability of energy).
2. Utilization of feed compounds which are not degradable by the endogenous animal enzymes.
3. Possible support of endogenous enzymes in degrading nutrients.

4. Diminishing environmentally relevant excretions, especially excretion of N and P.
5. Increase of the quality of meat products and yield in meat processing.
6. Improvement of birds welfare.

Some of these aims are the subject of the following discussion with consideration of the carbohydrases only.

Digestion capacity, qualitative and quantitative aspects

Effective application of exogenous enzymes to feed requires, in accordance with the mentioned aims, knowledge both about the compounds to be degraded in feedstuffs and the ability of the animal to degrade them. The activity of endogenous enzymes for degrading the main nutrients (protein, fat and carbohydrates) seems to be sufficient, and in most cases their degradation ability even exceed the amount of nutrients ingested (Simon et al., 1993; Wenk, 1993). However, in the case of fat digestion, poultry seems to lack the full ability to digest this nutrient in the first days of life as was indicated by Escribano et al. (1988) and Krogdahl and Sell (1989).

In case of carbohydrates, the need to distinguish between different classes of carbohydrates and their digestibility should be pointed out. Different enzymes are involved in degradation of carbohydrates. Endogenous enzymes, microbial enzymes and enzymes of plant origin play different roles in digesting carbohydrates. Only sucrose and starch are digested by endogenous enzymes, while microbial enzymes in the hindgut play a part in degrading carbohydrates not digested in the foregut. This microbial digestion provides mainly volatile fatty acids which can be used as an energy source by animal. These processes are connected with energy losses for the host. Enzymes of plant origin may support the digestion of starch or take part in a hydrolysis of water-soluble non-starch polysaccharides (NSP).

Physiological evaluation of cell wall components in cereal grains and protein feedstuffs of plant origin

Three main aspects are important in impairing the digestibility of nutrients and the metabolizability of energy. First, the components themselves may be undigestible. This aspect differs in its importance for the animal depending on the concentration of these components in the diet. Secondly, due to their chemical composition and physical structure some cell wall components include other digestible nutrients. This is the so-called "cage effect" and concerns all unsoluble cell wall components. It should be noted that many feed processing techniques result in disruption of the endosperm cell walls, and consequently,

Compound(s)	Occurence	Effect	Concerned animals
ß-glucan	Barley, oats, rye	Increase of digesta viscosity, disturbances in digestion and absorption, slower digesta passage, decrease in performance, moisty and sticky droppings	Chicks and other young birds, especially in the first weeks of life
Pentosans	Rye, triticale, wheat		Poultry, Piglets
Oligosaccharides (raffinose, stachyose, verbascose, ajugose)	Legume seeds, extracted rape and soyabean meals	Enhanced gas formation (CO_2, H_2, CH_4) in the hindgut; diarrhoea, flatulence	Monogastric animals

Figure 1. Antinutritive effects of carbohydrates

diminish the "cage effect" by improving the conditions for endogenous enzyme activity.

Regarding the practical use of exogenous enzymes, the third aspect has greater importance. The presence of soluble ß-glucans, pentosans and pectins leads to an increase in viscosity of the digesta, thus impairing digestion processes in general. The special effects of these antinutritive substances is shown in Figure 1. A consequence of these depressed digestion processes is decreased nutrients digestibility. There seems to be a negative relationship between the dietary fibre content (containing all cell wall components) and the digestibility coefficients of crude nutrients, which reflects all three described effects. Whereas the effect of the undigestible cell wall components is a quantitative one (the energy of the diet is diluted) the physiological and nutritional importance of the other two mentioned effects is a subject of discussion. Pettersson and Åman (1988) attributed the poor digestibility of barley-based diets rather to the "cage effect" than the viscosity of the soluble NSP. In contrast to that, investigations carried out on hull-less barley and oats, which had lower fibre content than the hulled varieties, brought the problems of viscosity of the soluble cell wall components into focus. Despite the higher gross energy of the hull-less cereals, poorer metabolizability of energy and decreased performance and digestibility of nutrients were observed. The increase in viscosity of digesta is accepted as the most pronounced effect diminishing the feed value of the diets rich in soluble NSP (Bedford, 1992).

TABLE 1

ß-glucan content in winter and spring varieties of barley from several European countries

Country	Crop	ß-glucan % of DM				Reference
		Winter	Spring	Mean	Range	
England	1983	3.49	4.14	3.82	2.24-5.03	Alexander and Fish (1984)
Scotland	1983	5.00	4.08	4.54	3.58-5.16	Alexander and Fish (1984)
Scandinavia	1981-1985	–	–	4.40	3.30-5.60	Åman and Graham (1987)
Finland	1988	–	3.70[1]/4.50[2]	4.10	3.60-4.60	Saastamoinen et al. (1991)
Lithuania	1991	2.93	3.75	3.34	2.76-4.11	Gruzauskas and Jeroch (1992)
Spain	1987	2.54	2.93	2.75	1.32-4.33	Francesch et al. (1989)
Spain	1988	3.19	2.92	3.06	1.50-4.56	Francesch et al. (1989)
Spain	1989	2.13	2.02	2.07	1.00-3.47	Perez-Vendrell and Francesch (1991)
Germany	1987	3.10/4.30	–	3.70		Jeroch et al. (1991)
Germany	1993	4.45[1]/3.70[2]	–	4.07	3.52-5.02	Stock and Jeroch (1995)
	1994	3.35[1]/3.35[2]				
		–	–	3.35	2.83-3.95	

[1] 2-row varieties
[2] 6-row varieties

TABLE 2

Pentosan content of wheat

Country	Crop	Pentosans % of DM				Reference
		Total		Soluble		
		Mean	Range	Mean	Range	
Sweden		5.80/6.30	–	–	–	Hesselman (1989)
Australia	1989/90	–	5.72-8.18			Annison (1990)
		5.42	–	0.52	–	Batterham et al. (1988)
Germany	1992/94	7.50	5.10-8.30	1.00	0.80-1.30	Jeroch (1994)
Lithuania	1993	6.44	6.10-6.78	1.23	1.08-1.43	Seskeviciene et al. (1994)
The Netherlands		–	–	0.80	0.59-1.00	Veldman and Vahl (1993)
UK		7.53	–	1.34	–	Henry (1987)

Content of antinutritive NSP in wheat and barley

Among the cereal grains, barley and wheat are important energy sources for poultry. However, these feedstuffs contain such amounts of antinutritive NSP which made it necessary to limit their use in poultry diets when no carbohydrase is supplemented. The extent of such limitation depends on the poultry species, age of birds and the content of soluble and total NSP. The total ß-glucan (mixed linked (1→3) (1→4)-ß-D glucans) content in barleys from different areas are listed in Table 1. Many factors may influence the ß-glucan content in barleys as is indicated by the wide range of its concentrations. Francesch et al. (1992) succeeded in proving the influence of environment (location and year) and the variety of barley grown in Spain on its ß-glucan content, viscosity and, consequently, on the apparent metabolizable energy (AME) content in the order up to 583 kcal/kg. Other factors, which may have influence on the ß-glucan content are harvest time and the extent of fertilization. There seems to be a correlation between total and soluble ß-glucans on one hand and between soluble ß-glucans and viscosity of digesta on the other hand, as indicated by the results from Rotter et al. (1990). These correlations are not close, because there are methodological difficulties in measuring the solubility of NSP, and the conditions during solubility determination may differ from that in the alimentary tract of the animal. The values for the total and soluble pentosan (arabinoxylans) content in wheat are shown in Table 2. It becomes clear that wheat, too, contains marked amounts of pentosans which may impair performance of the chicks.

Results of experiments with enzyme supplemented diets

Broilers

Although the conventional fattening time for broilers comprises 5 to 7 weeks, the test period frequently lasts only 14 to 21 days, beginning immediately or a few days after hatching. The rises in performance achieved in these short-term trials are often unusually high, however, they are not representative for the whole fattening period. The assessment of the enzyme effect usually decrease with increasing age, which can be explained by stabilization and adjustment of the microflora in the digestive tract to the feed. For this reason, practical recommendations should be derived only from experiments that included the whole fattening period with observance of standardized conditions. A recent evaluation of experiments made by well-known research teams in European countries and Canada furnished the results of Table 3. The enzyme effects were

TABLE 3
Effect of enzyme supplementation on performance of chicks fed barley, rye, triticale or wheat based diets

Reference	Cereals, in % of diet	Performance, in % of control	
		Final body weight	Feed conversion ratio
Brufau et al. (1991)	35/45* barley, 22/16* maize	102.5	98
Elwinger and Teglöff (1991)	50 barley, 11 wheat, 10 oats	101.5	99
Jeroch et al. (1991)		104	96.5
Jeroch et al. (1995)	68 barley	101.5	97.5
Rotter (1990)	68.3 barley	104	96
Salih et al. (1991)	59.6/65.8 barley	110.5	92.5
Francesch et al. (1994)	60/70 naked barley	100	97
Vukic Vranjes and Wenk (1993)	40/45 barley, 40 barley	104	95
Vukic Vranjes and Wenk (1995)	40 barley, 11.7 maize	106	94
Brufau et al. (1993b)		102-103[1)]	100-99[1)]
Gippert et al. (1994)	40 barley, 11.7 maize, 30 barley	103	96
Broz and Canterranne (1990)	20 rye, 40 wheat	106.5	94
	40 rye, 25.4 wheat	112.5	93.5
			94-93.5[1)]
Jackisch and Jeroch (1990)	31 rye, 31 maize	105.5-114[1)]	99-94[1)]
Jackisch and Jeroch (1992)	15.5 rye, 46.5 maize	104-108	94.5
Pettersson and Åman (1988)	57 rye	134	92
	30 rye, 28 maize	110	98-94[1)]
Richter et al. (1990)	20/30 rye, 38/35 maize	101-109[1)]	
Broz (1991)	50 triticale	100.5-102.5[1)]	99.5-98.5[1)]
Petterson and Åman (1988)	57 triticale, 4 maize	103	97.5
Richter et al. (1990)	40/60 triticale	100.5-102.5[1)]	99-98.5[1)]
	19/7 maize	102.5-108.5[1)]	98.5-93.5[1)]
Scholtyssek and Knorr (1987)	50 triticale	105.5	
	30 triticale, 20 maize		97.5
Carré et al. (1992)	49.7/56 wheat	102-107.5[1)]	97.5-93.5[1)]
Edney et al. (1989)	59.6-66.6 wheat	100	100
Jeroch et al. (1993)	61-64 wheat	101-103[1)]	98-96[1)]
McNab et al. (1993)	66 wheat	100.5	98
Schurz et al. (1995a)[3)]	60.4/64.4 wheat	(97)-104	(101)-95
Pettersson and Åman (1988)	57 wheat, 4 maize	103	99.5
Schutte et al. (1993)	50 wheat	102	96.5
Francesch et al. (1994)	40/45 wheat	100	97.5
Veldman and Vahl (1993)	40 wheat	100-102[2)]	99-97[2)]
	15 wheat, 30/45 wheat	100/101/102	99/99/98
Vukic Vranjes et al. (1994)	44 wheat, 22 maize	101	98

[1)] in dependence on enzyme dosage
[2)] in dependence on wheat variety
[3)] four experiments with different enzyme dosage, without or with antibiotic supplementation
* Starter/Finisher

mainly rather low, yet, their order was economically relevant. Above that, when rating enzyme preparations, sanitary, environmental and quality effects must be taken into account which will be elucidated below. Compared with the comprehensive trials on broiler chicks, few experiments have been made on poults and young water fowl.

Laying hens

Results from the literature on response to barley-containing layer diets are presented in Table 4. One may conclude from this survey that enzyme supplementation to barley-enriched layer diets does not influence the performance of hens. This fact may be attributed to the discussed relationship between the age of the birds and their susceptibility to the gel-forming ß-glucans of barley. In recent experiments Brufau et al. (1994) found a significant increase in egg weight for hens fed the enzyme-supplemented barley-containing diets (Table 4). This effect was pronounced only in the early laying period until 34 weeks of age which was attributed to a possible improvement in digestibility of nutrients for young hens. Authors noted also a significant decrease in the water to feed ratio when enzymes were added to the barley diets, what was connected with lower viscosity of the digesta.

Decreased water consumption was also observed when barley-enriched diets supplemented with carbohydrases were fed to broilers (Francesch, 1991; Jeroch et al., 1995a). Bedford (1992) also demonstrated a decrease in digesta viscosity of laying hens fed enzyme supplemented wheat- or rye-based diets. The extent in decrease of digesta viscosity was more pronounced for the rye-fed hens than for the wheat-fed hens which was caused by the higher pentosan content of rye. High barley content in laying hen diets may contribute to the incidence of dirty eggs and sticky droppings (Herstad, 1987). After supplementation of such diets with ß-glucanases this danger may be avoided.

Turkeys

In agreement with the results observed on broilers, an improvement in the performance of turkeys was found in some experiments with enzyme-supplemented barley or wheat diets (Table 5).

Water fowl

An increase in performance was also observed for geese and ducks when barley-based diets were supplemented with enzyme preparations (Table 6).

TABLE 4

Results of trials with enzyme supplemented barley diets for laying hens

Reference	Trial no	Barley in % of diet	Enzyme	Strain	Test period (days)/start of test at	Rate of lay, %	Egg weight g	Egg mass/hen/day g	Feed/egg kg/kg
Aimonen and Näsi (1991)	1	0-66.9	–	White Leghorn hybrids	168/LW 31	83.3	59.7	49.6	2.32
			+[1]			85.1	59.5	50.6	2.25
Benabdeljelil (1991)	1	35	–	Tetra	56/LW 30	90.0	60.1	54.1	2.11
			+[2]			86.2	59.8	51.5	2.18
	2	35	–	Tetra	567/LW 30	89.6	58.8	52.7	2.16
			+[2,3]			89.9	58.0	52.1	2.21
Brufau et al. (1994)	1	68.9	–	ISA-Babcock B	110/LW 21	82.6	58.2	48.1	2.37
			+[4]			84.3	58.8	49.6	2.22
Gruzauskas et al. (1991)	1	50	–	White Leghhorn	274/LW 22	78.0	58.0	45.2	2.62
			+[5]	hybrids		81.0	57.0	46.2	2.57
	2	70	–	White Leghorn	274/LW 22	77.0	57.0	44.0	2.68
			+[5]	hybrids		80.0	56.0	44.8	2.59
Jeroch (1991)	1	70.9	–	White Leghorn	353/LW 23	82.0	58.7	48.2	2.49
			+[6]	hybrids		82.0	58.4	47.9	2.52
	2	70.9	–	White Leghorn	112/LW 22	83.2	62.6	43.8	2.63
			+[6,7]	hybrids		86.6	53.2	46.1	2.52
Näsi (1988)	1	36-61	–		280/LM 2-12	75.1		49.0	2.39
			+[8]			74.8		48.6	2.38
	2	36-61	–		56/LM 14-15	58.9		39.2	3.13
			+[9]			60.8		40.5	2.99

[1] multienzyme preparation Avizyme (1 g/kg)
[2] multienzyme preparation Kemzyme (0.5 g/kg)
[3] multienzyme preparation SP 343 (0.5 g/kg)
[4] multienzyme preparation Roxazyme (100/200 mg/kg)
[5] multienzyme preparation MEK-GPL (100 U ß-glucanase/kg)
[6] multienzyme preparation Prowiko B 1000 S (1000/2000 U ß-glucanase/kg)
[7] lysozym G3x (900 U cellulase/kg)
[8] ß-glucanase 1 g/kg)
[9] multienzyme preparation (1 g/kg)
LW – life week LM – laying month

TABLE 5

Results of trials with enzyme supplemented turkey diets

Reference	Cereal, % in diet	Enzyme preparation	Dosage/kg feed	Test period, days	Performance, in % of control	
					Final body weight	Feed conversion ratio
Müller and Jeroch (1990)	Barley 50→75[1]	Prowiko B 1000 S	1000 U	1-84/112	100-103	100-97
Völker and Tüller (1993)	Wheat 40→70[1]	Roxazyme G	150 mg	1-146	**104**	96
	Barley/wheat (50:50) 40→70[1]	Roxazyme G	150 mg	1-147	**106**	95
Hamilton (1994)	Naked oats 30	ß-glucanase	1000 mg	1-28	100	100
Lehmann et al. (1995)	Wheat	ZY 28[2] ZY 88[3]	300/600 mg 200 mg	1-77	100-101	98-99
Richter (1994)	Wheat 46.5→86.5[1]	ZY 28[2] ZY 88[3]	500/1000 mg 100/200 mg	1-140	100.5-103	95

[1] increasing cereal percentages from the beginning until the end of the fattening period
[2] xylanase, ß-glucanase
[3] protease

TABLE 6

Results of trials with enzyme supplemented barley based water fowl diets

Reference	Species	Trial	Barley in diet (%)	Enzyme	Test period, days	Final body weight, g *% of control*	Feed conversion ratio, kg/kg *% of control*
Jeroch and Engerer	Geese	1	65[1]/78[2]	–	1-56	4512 *100*	2.99 *100*
(1992)				+[4]		4684 *104*	2.97 *99*
		2	65[1]/78[2]	–	1-56	4405 *100*	2.70 *100*
				+[4]		4478 *102*	2.78 *103*
Jeroch et al.	Muscovy	1	73[1]/79[3]	–	1-77	4221 *100*	2.97 *100*
(1995b)	ducks		85[3]	+[5]		4442 *105*	2.95 *99*
		2	73[1]/79[2]	–	1-77	4358 *100*	2.91 *100*
			85[3]	+[6]		4544 *104*	2.83 *97*
		3		–	1-77	4156 *100*	2.92 *100*
				+[7]		4245 *102*	2.93 *100*
Schurz et al.	Pekin ducks	1		–	1-48	2852 *100*	2.51 *100*
(1995b)				+[6]		3043 *107*	2.50 *100*

[1] starter
[2] grower
[3] finisher
[4] multienzyme Prowiko B 1000 S (1000 U ß-glucanase/kg feed)
[5] 500 mg ZY 28/kg
[6] 150 mg Roxazyme/kg feed
[7] 75/150/300 mg Roxazyme/kg feed

Mode of action of supplemented carbohydrases

Metabolizability of energy

The latest experiments on broilers, mainly with barley and wheat rations (high-pentosan wheat varieties) in form of pellets were marked by an almost unchanged feed intake compared with the standard groups. In some experiments, including ours, the chicks fed enzyme supplemented diets consumed even less feed than chicks fed unsupplemented diets. Higher weight gains were linked with improved feed/gain ratios. For these experiments the improved growth of the animals can only be explained by better energy and nutrient metabolizability, since there were hardly any differences in the body composition between "standard" and "enzyme" broilers. In some cases, broilers fed the enzyme-supplemented diets were a little fatter as a result of greater energy supply.

In growth tests combined with measurements of the metabolizability of energy a direct relationship between the performance and the influence of the supplemented enzymes on metabolizable energy of diet may by established. Thus Carré et al. (1992) and Gippert et al. (1994) succeeded to prove in broiler growth tests with wheat or barley diets that an increase in final fattening weight and feed/gain ratio after a 42-day fattening period was also accompanied by higher metabolizability of energy (Table 7). The measurements of the influence of feed enzymes on the content of metabolizable energy in grains or grain-enriched feed mixtures furnished rather discrepant results. The evaluation of experiments with barley and barley-enriched mixtures revealed an energy increase by 1.5-15 % for barley and 0-41% for barley-enriched mixtures (Table 8). This enormous variation may have different causes. An essential factor might be the varying

TABLE 7

Effect of enzyme addition to wheat or barley based broiler rations on performance of birds and on AME_N values (Carré et al., 1992, Gippert et al., 1994)

Enzyme	Live body weight*		Feed: gain		AME_N	
	g	%	kg/kg	%	MJ/kg	%
–	1624	*100*	2.23	*100*	11.23	*100.0*
+[1]	1736	*107*	2.09	*93.5*	11.96	*106.5*
–	1576	*100*	2.29	*100*	12.57	*100*
+[2]	1629	*103*	2.20	*96*	12.83	*102*

[1] enzyme preparation BioFeed Plus with mainly pentosananase activity
[2] 100 mg Avizyme/kg
* at 42nd day

TABLE 8

Influence of ß-glucanase preparations on the content of metabolizable energy of barley or barley based diets to broilers

Reference	Barley type	– Enzyme	+ Enzyme	Change (%)
Aboud et al. (1990)	6 row, hulled[1]	13.4	13.6	+1.5
Brufau et al. (1993)	6 row, hulled[1, 5]	12.77	13.36	+5
	2 row, hulled[1, 5]	13.69	13.74	0
Jeroch et al. (1995a)	6 row, hulled[1]	13.0	13.7	+5
Rotter et al. (1990)	Hull-less[1]	11.1	13.9	+13
	Hulled[1]	12.6	12.8	+1.5
Rutkowski (1992)	Hulled[1]	13.1	12.9	−1.5
Aboud et al. (1990)	6 row, hulled[1]	11.6	11.8	+1.5
Broz and Frigg (1986)	Hulled[2]	12.4	12.7	+2
Friesen et al. (1992)	Hulled[2]	14.8	15.8	+7
	Hull-less[2]	11.4	16.1	+41
Francesch et al. (1994)	2 row, hulled[2]	13.3[3]	13.48[3]	+1.5
	2 row, hulled[2]	13.03[4]	13.41[4]	+3
McNab (1993)		11.54	12.04	+4
Vukic Vranjes and Wenk (1995)	[2, 4]	14.33	14.56	+1.6

[1] barley
[2] barley based diets
[3] coarse meal
[4] pellets
[5] mean of values for 0.6 and 12 month of storage

content of soluble NSP in the cereal species or diets and the viscosity ensuing therefrom. In most cases higher viscosity of the hull-less compared to the hulled barley varieties was observed (Rotter et al., 1990; Friesen et al., 1992).

The energy value of wheat-based and wheat-enriched diets also increase after enzyme supplementation (Carré et al., 1992), (Table 9). This substantiated the investigations by Annison (1991, 1992) which proved beyond doubt that variations in the content of metabolizable energy of Australian wheat varieties (11.25-13.59 MJ/kg DM) are connected with varying concentration of water-soluble NSP. The Australian research team attributed the differences in the content of metabolizable energy for chicks between cereal species principally to the varying concentrations of NSP (pentosans and ß-glucan) (Figure 2). The correlation between NSP content in cereals and the metabolizability of energy is

TABLE 9

Influence of enzyme supplementation to a wheat based diets on the content of metabolizable energy for broiler chicks, AME_N, MJ/kg

Reference	Diet	– Enzyme	+ Enzyme	Change (%)
Annison (1992)	Wheat based	14.26	15.45	+8
Carré et al. (1992)	Wheat based	12.54	13.35	+6
Friesen et al. (1992)	Wheat based	14.13	14.71	+4
McNab (1993)	Wheat	14.48	15.43	+7
		14.4	15.26	+6
Brufau et al. (1992)	Wheat 40 %, maize 15%	13.31	13.88	+4
Francesch et al. (1994)	Wheat 40 %, maize 21%	14.12[1]	14.25[1]	+1
		13.6[2]	13.6[2]	0

[1] coarse meal

[2] pellets

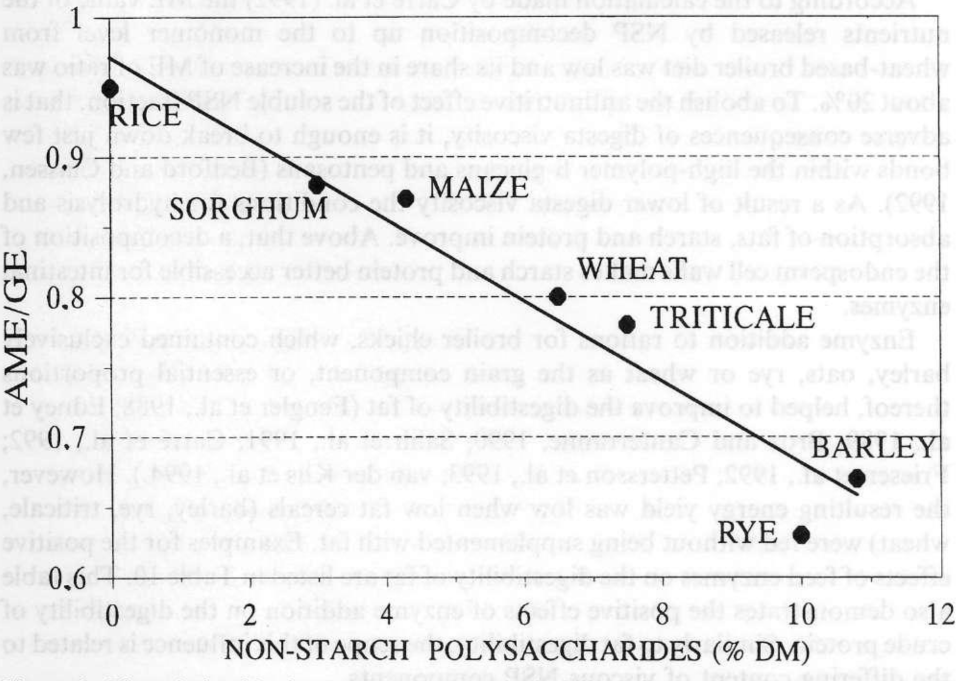

Figure 2. The relationship between energy metabolizability of cereals and their non-starch polysaccharide composition (pentosan + ß-glucans, % dry matter) (Choct and Annison, 1990)

high indeed, and there is no doubt that pentosans and ß-glucan affect decisively the availability of energy. Yet, oats do not fit in this pattern. Despite an approximately equal content of antinutritive NSP like in barley, its ME content is remarkably lower. In oats beside specific NSP with antinutritive effects there are other cell wall components that affect the metabolizability of energy.

Digestibility of feed nutrients

According to the available literature, different processes are responsible for the improved availability of energy connected with NSP-decomposing enzyme activities:
- NSP hydrolysis to monomers (D-glucose, D-xylose, L-arabinose),
- improved starch digestibility,
- higher fat digestibility,
- improved protein digestibility.

The energy gain results only partially from NSP hydrolysis to resorbable monosaccharides.

According to the calculation made by Carré et al. (1992) the ME value of the nutrients released by NSP decomposition up to the monomer level from wheat-based broiler diet was low and its share in the increase of ME of ratio was about 20%. To abolish the antinutritive effect of the soluble NSP fraction, that is adverse consequences of digesta viscosity, it is enough to break down just few bonds within the high-polymer ß-glucans and pentosans (Bedford and Classen, 1992). As a result of lower digesta viscosity the conditions for hydrolysis and absorption of fats, starch and protein improve. Above that, a decomposition of the endosperm cell walls makes starch and protein better accessible for intestinal enzymes.

Enzyme addition to rations for broiler chicks, which contained exclusively barley, oats, rye or wheat as the grain component, or essential proportions thereof, helped to improve the digestibility of fat (Fengler et al., 1988; Edney et al., 1989; Broz and Canterranne, 1990; Salih et al., 1991; Carré et al., 1992; Friesen et al., 1992; Pettersson et al., 1993; van der Klis et al., 1994.). However, the resulting energy yield was low when low fat cereals (barley, rye, triticale, wheat) were fed without being supplemented with fat. Examples for the positive effects of feed enzymes on the digestibility of fat are listed in Table 10. This table also demonstrates the positive effects of enzyme addition on the digestibility of crude protein. Similarly to fat digestibility, the scope of this influence is related to the differing content of viscous NSP components.

Improved crude protein digestibility was reported by Broz (1987), Broz and Canterranne (1990) and Pettersson et al., (1993) for rye-containing diets, by

TABLE 10

Effect of enzyme preparation on metabolizable energy and nutrient digestibility of barley or barley based diets for broiler chicks

Reference	Type of barley	Enzyme	ME, MJ/kg DM	Digestibility, %	
				crude protein	crude fat
Friesen et al. (1992)	Hulled	–	14.8	83.0	75.2
		+	15.8	87.0	85.0
	Hull-less	–	11.4	66.8	43.2
		+	16.1	86.5	79.9
Almirall et al. (1993)	Low-viscosity	–		74.1	76.7
		+		83.4	80.8
	High-viscosity	–		69.4	75.4
		+		80.9	78.8
Jeroch (1994)	Hulled	–	12.6	74.5	74.7
		+	13.2	81.0	78.3

Carré et al. (1992) for a wheat diet and by Rotter et al. (1990) for rations based on barley, oats and rye. In contrast to this, practically no improvement of crude protein digestibility after enzyme addition was found by Aboud et al. (1990) with barley and barley-enriched feed rations.

Enzyme additives helped also to improve the digestibility of cereal starch when grain crops or single varieties with increased NSP concentration were fed. Carré et al. (1992) reported a rise of starch digestibility from 95 to 98 % when broiler chicks were fed wheat-enriched diets. Annison (1992) reported that the ileal digestibility of the starch in wheat rations improved after enzyme addition from 88 to 96-98%. Equally evident was the increase of starch digestibility in a diet containing rye endosperm (Pettersson et al., 1993).

Digesta passage rate and feed intake

An enzyme-conditioned decrease of the digesta viscosity may entail faster feed passage. Investigations by Salih et al. (1991), Almirall and Esteve-Garcia (1994) and also our own experiments, carried out with barley-based rations with or without enzyme supplementation, demonstrated accelerated passage of the digesta (Figure 3). This enables a higher feed intake as was recorded in numerous experiments. The involved increase in the energy and nutrient supply might be an essential factor for the intensified growth of broilers fed enzyme-supplemented diets.

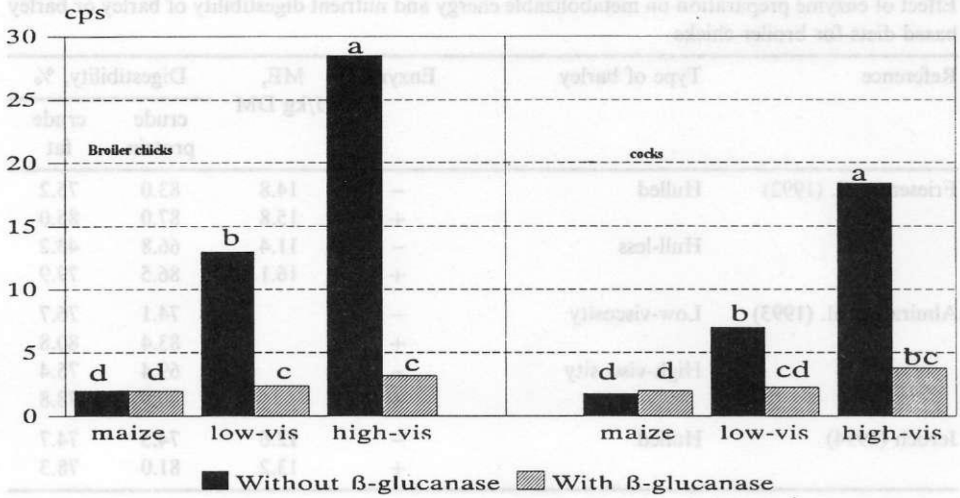

Figure 3. Passage time of barley based diets fed to broiler chickens (Jeroch et al., 1990)

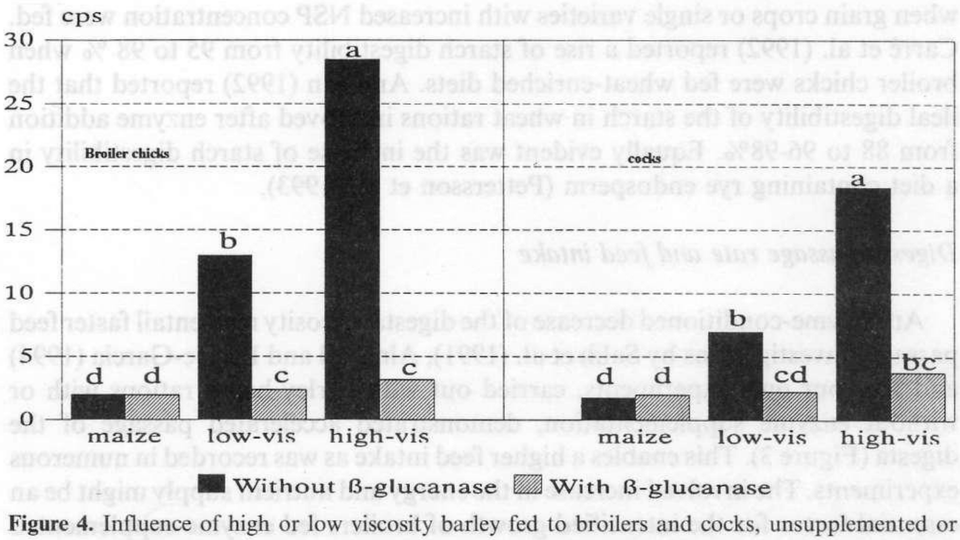

Figure 4. Influence of high or low viscosity barley fed to broilers and cocks, unsupplemented or ß-glucanase-supplemented, on the foregut viscosity (Almirall et al., 1993)

Digesta viscosity

The repeatedly mentioned rise in digesta viscosity after the application of feedstuffs or feed mixtures containing soluble NSP can be excluded by substrate-specific enzyme preparations. The effect of enzyme containing xylanase and ß-glucanase acitivities was particularly impressive in tests by Bedford and Classen (1992) with rations in which wheat was gradually substituted by rye. For barley-enriched diets Aboud et al. (1990), Salih et al. (1991) and Almirall et al. (1993) succeeded in showing the viscosity-lowering effect of added ß-glucanase. In addition, Almirall et al. (1993) demonstrated the age-effect on digesta viscosity in barley feeding and its reduction by enzyme supplementation (Figure 4).

Demands for enzyme preparations

According to Simon et al. (1993), because of the nature of the digestive tract and feed technology, exogenous feed enzyme should fulfill special demands:

1. High thermostability.
   This aspect plays an important part in processing poultry feed, especially in process of pelleting as high temperature in process of pelleting decreases the activity of feed enzymes. Protection of enzymes by technical and technological means is a challenge for enzyme producers (Sasserod, 1993).
2. Maintenance of activity in the acidic pH range and high pH-stability.
   There is a wide range of changing pH values throughout the alimentary tract and enzymes should maintain their activity after passing through the stomach (lowest pH) to be effective in the foregut.
3. No toxicological concerns.
   As to the discussed specificity of enzymes with regard to their substrates it is recommendable to use enzymes or enzyme cocktails with activity closely fitted to the known substrates of feed or diet. Only in this way it becomes possible to overcome the heterogeneous experimental results discussed above.

Benefits of exogenously supplemented enzymes

Chicks that are fed barley, oat or rye rations void watery and sticky excreta. The altered faeces stick to the anus, pollute plumage, feeding and drinking facilities, deteriorate litter and housing climate. These grave disadvantages are much more expressed in practice than in the laboratory experiments. Enzyme addition to rations containing risky cereals may help to reduce or avoid the described problems. Even when high rye proportions (30%) were incorporated in the broiler diet, excreta consistency after enzyme addition corresponded to that of maize-fed animals (Jackisch and Jeroch, 1990). The stickiness of faeces on barley rations can also be drastically reduced by enzyme supplementation (Brufau et al., 1991, Elwinger and Teglöf, 1991). Therefore, it is important to assess the effectiveness of enzyme preparations not only on the basis of growth improvement and the decrease of the feed/gain ratio. Enzyme addition induced also a decline in the number of dirty chicks as well as lower water consumption (Brufau et al., 1991; Jeroch et al., 1995a). Thus, enzyme supplementation may lead to better sanitary and environmental conditions and to reduction of production risk.

CONCLUSIONS

Exogenous enzyme supply may improve quality and feeding effect of feed mixtures containing cereals with antinutritively acting NSP. As shown in comparative trials, the same fattening results are possible as with mixtures based on maize. Feed producers and farmers may incorporate greater proportions of risky cereals in poultry rations when feed enzymes are added.

Table 11 gives recommendations for the input of such cereals with and without enzyme addition. The results obtained with enzyme-supplemented wheat rations have again raised the question about the NSP threshold in the feed beyond which antinutritive effects must be expected. The dosage of enzymes is important mainly from the economical point of view, and should be related to the proportion of soluble NSP in feed mixture. The doses applied in the majority of experiments represent only orientation aids for practical conditions, because feed

TABLE 11

Limits for cereal percentages in mixed feeds for gallinaceous birds

Strain	Barley		Oats		Rye		Triticale		Wheat	
Enzyme	–[2]	+	–[2]	+	–[2]	+	–[1,2]	+	–[1,2]	+
Chicks	10	40	10-30[3]	n.l.[3]	5	20	20	n.l.	30	n.l.
Pullets	30	n.l.	20-30	n.l.	15	30	30	n.l.	40	n.l.
Layers	60	n.l.[4]	20	40	20	40	30	n.l.	40	n.l.
Broiler chickens	10	40	10-30[3]	n.l.[3]	5	20	20	40	20	n.l.

n.l. = no limit

[1] varieties with lower energy and higher pentosan content

[2] recommendations only for diets without any feedstuffs containing critical specific NSP

[3] husked

[4] improved egg quality and litter condition after enzyme addition

mixtures in practice are normally based on more components than in most experiments. In view of the remarkably varying NSP content in single cereal crops (for example the ß-glucan in barley, pentosan in wheat) an uncomplicated approach to the assessment of the antinutritive potential of NSP would be desirable. A suitable criterion might be the extract viscosity which correlates closely with the soluble NSP content. Unfortunately, the experiments run so far do not allow drawing generally acceptable conclusions because, among other reasons, the data of the available measuring principles are not comparable. The investigations hitherto performed demonstrated that enzyme preparations are able to hydrolize NSP only to a minor extent to resorbable monomers. In contrast to the avoidance of antinutritive effects, the challenge to fermentative decomposition is much greater here.

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STRESZCZENIE

Wpływ preparatów enzymatycznych na wartość odżywczą zbóż dla drobiu

Dodatek preparatów enzymatycznych do mieszanek zbożowych dla drobiu może znacznie poprawić wyniki produkcyjne oraz obniżać lepkość treści przewodu pokarmowego. Jednak końcowy efekt zależy w dużym stopniu od zawartości w mieszance niektórych polisacharydów nieskrobiowych (NSP) oraz od wieku ptaków. W pracy podano średnią zawartość NSP wykazujących działanie antyżywieniowe w jęczmieniu, pszenicy, pszenżycie i życie oraz przedyskutowano ich wpływ na procesy zachodzące w przewodzie pokarmowym ptaków w różnym wieku, jak również wpływ enzymów egzogennych dodawanych do mieszanek na te procesy.