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EFFECT OF MECHANICAL PROCESSING OF CEREALS ON RUMEN STARCH DEGRADABILITY

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Abstract

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Although starch in cereal grain is almost completely digested in the whole digestive tract, the rate and extent of ruminal degradation and fermentation vary widely with grain source and cereal processing. The objective of this study was to determine the effect of particle size (≤ 1.4, 1.5–2.5, 2.6–3.0 and > 3.0 mm) of mechanically processed wheat, barley and maize on ruminal degradation of starch. Standardized *in sacco* method was used to determine the degradation of starch in mechanically processed grains with incubation times of 0, 3, 6, 9, 16, 24, and 48 hours for maize, respectivelly. Significant differences of starch effective degradability (EDg) were determined among experimental feeds as well as dependence on particle size of feeds. Among cereals, wheat had the highest effective starch degradability (83.0–95.2%), the lowest was found for maize (52.1–76.1%). Effective degradability of starch was the highest for the smallest particles (≤ 1.4 mm), 95.2 for wheat, 91.2 for barley and 76.1% for maize. The effective degradability of starch was decreased with enlarging of particle size of used grains. These results indicate that optimal degree is coarsely grinding, because larger particles increased passage of starch to the duodenum.

cereals, grain processing, starch, *in sacco* degradability

Starch is a primary nutrient of those ruminant diets used to promote high levels of production. Optimal starch utilization is fundamental to improve efficiency of animal production. The main sources of starch in the diets are the cereals, commonly barley, corn and sorghum (Theurer, 1986).

Degradation variability of saccharides influences the fermentation processes in the rumen, passage of nutrients into the small intestine and nutrients digestibility (Pajtáš and Šimko, 2003; Šimko *et al.*, 2008).

Although starch in cereal grains is almost completely digested in the digestive tract, the rate and extent of ruminal fermentation varies widely with grain source and processing of cereals (Owens *et al.*, 1986; Huntington, 1997). For most kinds of grain, except corn and sorghum, at least 90% of starch is fermented in the rumen. With corn, up to 30% or more could escape ruminal fermentation; most of starch escaping fermentation would be digested in the small intestine or fermented in the large intestine.

Whole kernels with an intact pericarp are very resistant to bacterial colonization and penetration of starch granules. The first goal of mechanical processing is to break the outer coat of the grain and increase microbial access to starch, and consequently to increase rumen and total tract starch digestion (Rémond *et al.*, 2004). Partical size reduction increases the surface available for adhering of microbial population and provides more substrate for amylase activity (Nocek and Tamminga, 1991; Offner *et al.*, 2003). The objective of the present study was to evaluate the effect of particle size of cereal grains on the ruminal starch degradation.

MATERIALS AND METHODS

Standardized *in sacco* method (Harazim and Pavelek, 1999) was used to determine the degradation of starch in mechanically processed grains of wheat, barley and maize with incubation times of 0, 3, 6, 9, 16, 24 hours, and 48 hours for maize, respectivelly. The parameters of starch degradation and effec-

I: *Particle size of experimental feeds*

screen size of sieves (mm)	particle size (mm)	share of fraction after grinding of 1 kg meal (%)		
		wheat	barley	maize
1.4	≤ 1.4	33.93 (P1)	29.77 (J1)	19.64 (K1)
2.5	1.5–2.5	30.62 (P2)	35.68 (J2)	59.17 (K2)
3.0	2.6–3.0	19.46 (P3)	20.25 (J3)	11.81 (K3)
	> 3.0	15.99 (P4)	14.30 (J4)	9.38 (K4)

tive degradation were calculated using the Neway programme (Rowett Research Institute) based on the equations described by Ørskov and McDonald (1979). An outflow rate 0.06 and 0.08.h^{-1} was used in the calculation of effective starch degradation. Chemical composition of feeds and residues after incubations were determined by the Weende system analysis (STN, 1985). Starch was determined by the enzymatic method according to Salomonsson *et al.* (1984).

Maize (DK 471), winter wheat (Brea) and spring barley (Jubilant) were used as experimental material. Feed samples were processed by grinding in grain hammer mill. The samples of ground feeds were separated in a set of sieves to obtaining particles of different size (Table I).

Experiments were performed with two dry cows of Black Spotted breed. The animals (an average liveweight 645 kg) were fitted with a large rumen fistula (Ø 10.5 cm). Daily ration consisted of lucerne hay (4 kg), maize silage (6 kg), concentrates (2 kg, wheat and barley in ratio 1:1) and mineral-vitamin additive. Roughage represented 75% out of total dry matter content in ration. Level of nutrition did not exceed 1.5 times of maintenance requirement. Animals were fed twice daily (at 6.00 and 18.00) with free access to drinking water.

Basic statistical characteristics for individual studied factors (feed, treatment, incubation period) were calculated. Two and three way variance analyses were used for evaluation of the mentioned factors and their interactions. The significant interactions of feed x treatment and feed x incubation times, were depicted graphically. The linear and quadratic functions for relationship among starch degradation and particle size or incubation times were calculated. Applied mathematical and statistical models were in statistical package Statistix 8.0 by Grofik and Fľak (1990), and Microsoft Office Excel 2007 computer program was used for graphical processing.

RESULTS AND DISCUSSION

Among individual species and varieties of grain feeds there are differences in their degradation, resulting from chemical composition and physical structure, which becomes evident in the extent and rate of their change in the rumen (Matthé, 2001).

Lebzien and Engling (1995) referred that by wheat feeding, about 89% of starch is fermented in the rumen, by barley about 81% and only 69% maize.

Čerešňáková *et al.* (2003) determined significant differences in degradability of starch in various cereals fed to ruminants. The lowest degradability of starch was determined in maize grain and the highest one in wheat varieties.

The highest disappearance of starch in wheat and barley was determined during the first three hours of incubation, 43.8–93.5% for wheat and 45.3–93.3%

II: *Characteristics of starch degradability of processed feeds after incubation in the rumen*

Fraction	a %	b %	c %.h^{-1}	EDg (%)	
				0.06.h^{-1}	0.08.h^{-1}
P1	64.2	35.5	0.418	95.2	94.0
P2	23.3	76.4	0.429	90.3	87.7
P3	17.9	82.1	0.308	86.6	83.1
P4	16.7	81.6	0.260	83.0	79.1
J1	52.3	47.3	0.277	91.2	89.0
J2	18.0	82.0	0.160	77.6	72.7
J3	17.2	82.8	0.228	82.8	78.5
J4	16.6	83.4	0.141	75.1	69.8
K1	45.0	55.0	0.078	76.1	72.2
K2	25.4	74.2	0.072	65.9	60.5
K3	20.5	79.5	0.055	58.5	52.9
K4	12.2	87.8	0.050	52.1	46.0

a – Rapidly degradable fraction; b – Potentially degradable fraction; c – Rate constant of degradation; EDg – Effective degradability

for barley. With prolongation of incubation time to 24 hours degradation continued until it reached values from 94.30 (P4) to 99.30% (P1) for wheat and from 97.80 (variant J4) to 99.50% (J1) for barley. Starch disappearance from maize of different particles size was considerably lower than from wheat and barley during incubation times in the rumen. Starch degradation exceeded the limit of 90% after 48 hours of incubation only in K1 (particle size ≤ 1.4).

Galyean *et al.* (1981) reportet that particle size of ground corn after 8 hours of incubation had a little effect on starch disappearance from 6000, 3000, and 1500 µm particles (average 9.2%), but the effect of 750 µm particles on the extent of starch disappearance was higher (21.7%).

In our experiment linear and quadratic dependence of starch disappearance of individual feeds with different particles size and with regard to incubation period was also studied. Quadratic dependences were also represented graphically for better documentation of evidence (Figs. 1–3).

Faster rate of degradation of fraction "b" (0.260–0.429%.h^{-1}) and a high proportion of rapidly degradable fraction "a" was determined for wheat. The highest value of fraction „a" was in P1 (64.2%) and lower in P4 (16.7%) with an effective degradability from 83.0 (P4) to 95.2% (P1) (Table II). The level of effective degradability can be affected by the outflow rate (kd) of digesta from the rumen. Vérité et al. (1990) recommended apply for concentrates kd value 0.06–0.08.h^{-1}.

Linear relationship of starch disappearance from wheat on incubation time and particles size were statistically significant only for P4 and quadratic course of starch disappearance was significant for all particle size fractions (Table III, and Fig. 1).

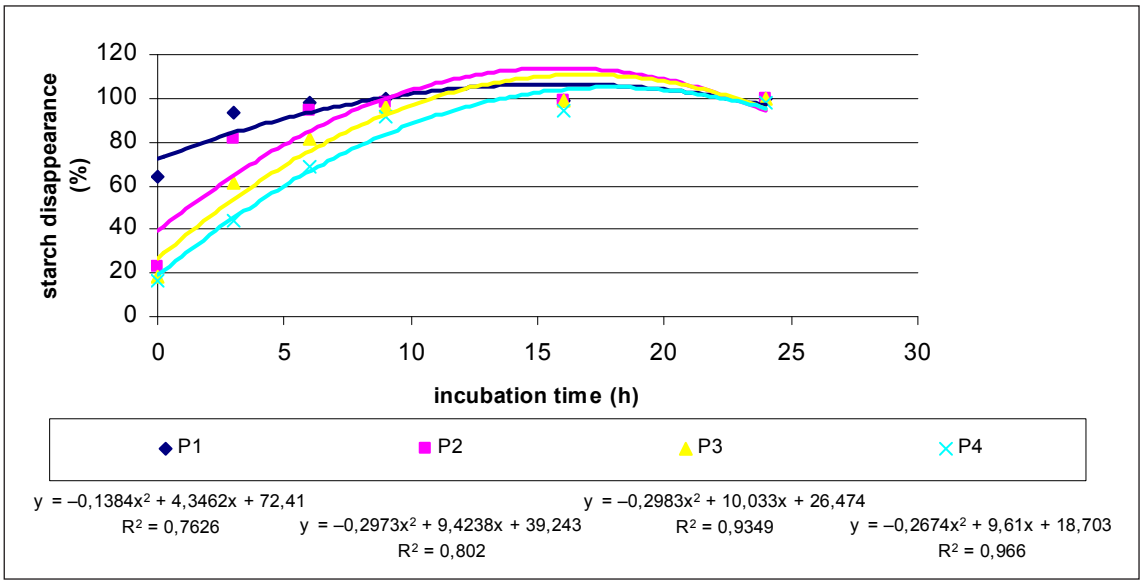
The effect of barley particle size (2770 µm, 2127 µm, and 1385 µm) on performance and digestion characteristics evaluated Bengochea *et al.* (2005). Total tract starch digestibility increased linearly ($P < 0.05$), and faecal starch output decreased linearly ($P < 0.05$) with reducing of particle size .

In our experiment, for barley was found a very high percentage of soluble and degradable fraction "a" (52.30% for J1), and degradation rate of fraction

III: *Summary of linear (L) and quadratic (Q) functions of starch disappearance from wheat influenced by incubation time and particle size*

Fraction n = 6	function	a	b	c	R^2	R^2_α
P1	L	82.7970	0.9870		0.3949	
	Q	72.4100	4.3462	–0.1384	0.7626	
P2	L	61.5600	2.2065		0.4311	
	Q	39.2430	9.4238	–0.2973	0.8020	
P3	L	48.8670	2.7918		0.6066	
	Q	26.4740	10.0330	–0.2983	0.9349	+
P4	L	38.2750	3.1188		0.7164	+
	Q	18.7030	9.6100	–0.2674	0.9660	++

$^{+}P<0.05$; $^{++}P<0.01$
$R_{0.05}(1.4) = 0.8110$ $R^2_{0.05}(1.4) = 0.6577$; $R_{0.01}(1.4) = 0.9170$ $R^2_{0.01}(1.4) = 0.8408$
$R_{0.05}(2.3) = 0.9300$ $R^2_{0.05}(2.3) = 0.8649$; $R_{0.01}(2.3) = 0.9770$ $R^2_{0.01}(2.3) = 0.9545$



1: *Quadratic relationship of starch disappearance between incubation time and particle size of wheat*

"b" varied from 0.141–0.277%.h^{-1}, with the highest value for J1 (Table II).

Quadratic dependence of starch disappearance from barley on incubation times and particle size (Table IV and Fig. 2) was statistically significant with the coefficients of determination from R^2 = 0.7509 (J1) to R^2 = 0.9693^{++} (J4).

Żebrowska *et al.* (1997) evaluated the degradability of cereals, which were ground on a mill to pass a 2 mm sieve. Starch degradation from winter barley was lower (85.9%) than the starch from spring barley (92.6%). The starch effective degradability was the highest for oats (99.1%) and for spring and winter wheat was similar (95.9% resp. 96.0%). This values are comparable with our results for variant P1 and J1 (particle size ≤ 1.4 mm).

A review of the literature showed that starch degradability in the rumen from ground corn ranged from 53.1 to 67% based on *in situ* and *in vitro* studies and from 51.4 to 93% based on *in vivo* studies (Nocek and Tamminga, 1991).

Philippeau *et al.* (1999) compared the effective degradabiliy of wheat and maize starch. Each kind of cereal was ground to pass a 3-mm sieve and ruminal starch degradability was lower for maize than for wheat ($P < 0.001$). The rapidly degraded starch fraction of wheat was high (86.9%), whereas maize had a high slowly degraded fraction (77.4%). The effective starch degradability was 98.2% and 72.7% for wheat and maize respectively.

Starch of maize grain is different in comparison with others cereal grains as regards ruminal starch degradation. Differences in the chemical and physical structure of starch granules determine the quality of starch in feeds and its degradability and availability. The rate of maize starch degradability is lower than in other cereals (Lebzien *et al.*, 1997; Philippeau *et al.*, 1999). Starch granules (especially in maize) are embedded in a protein matrix that protects starch granules from hydrolysis by amylolytic enzymes (Huntington, 1997). Zein represents main storage protein in maize, which is water-insoluble (Harper, 1979) because of their physical and chemical structure. Maize zein creates spatial structure by means of disulfidic bridges, which restrains entry of hydrolytic enzymes, and reduces not only the degradabi-

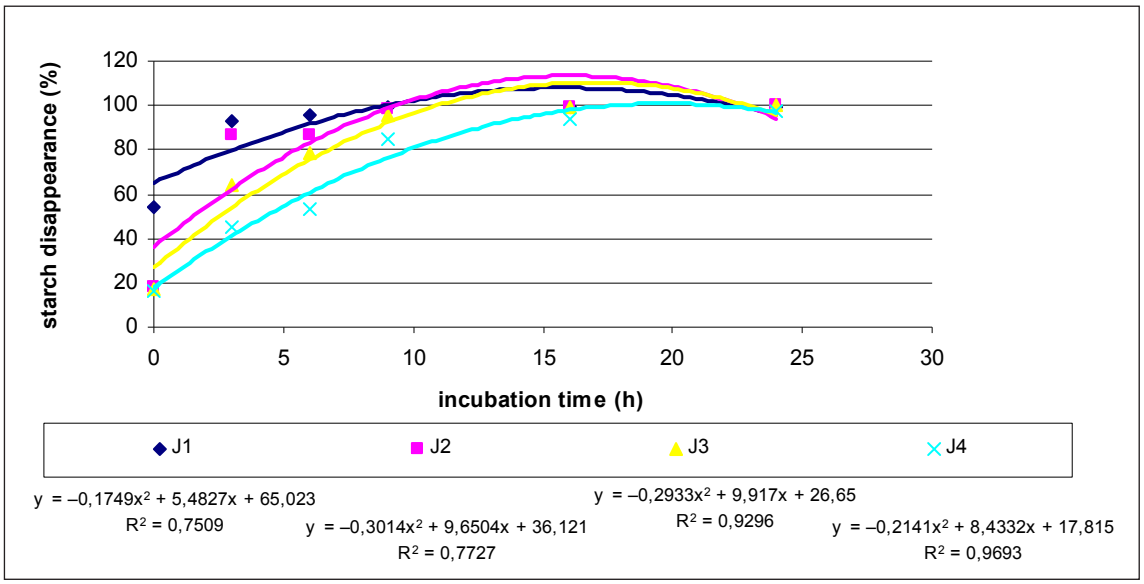
IV: *Summary of linear (L) and quadratic (Q) functions of starch disappearance from barley influenced by incubation time and particle size*

Fraction n=6	function	a	b	c	R^2	R^2_α
J1	L	78.1510	1.2373		0.3857	
	Q	65.0230	5.4827	–0.1749	0.7509	
J2	L	58.7420	2.3351		0.4319	
	Q	36.1210	9.6504	–0.3014	0.7727	
J3	L	48.6620	2.7984		0.6114	
	Q	26.6500	9.9170	–0.2933	0.9296	+
J4	L	33.8890	3.2351		0.8026	
	Q	17.8150	8.4332	–0.2141	0.9693	++

$^{+}P<0.05$; $^{++}P<0.01$

$R_{0.05}(1.4) = 0.8110$ $R^2_{0.05}(1.4) = 0.6577$; $R_{0.01}(1.4) = 0.9170$ $R^2_{0.01}(1.4) = 0.8408$

$R_{0.05}(2.3) = 0.9300$ $R^2_{0.05}(2.3) = 0.8649$; $R_{0.01}(2.3) = 0.9770$ $R^2_{0.01}(2.3) = 0.9545$



2: *Quadratic relationship of starch disappearance between incubation time and particle size of barley*

lity of crude protein but also starch (Kotarski *et al.*, 1992).

High values of degradable, but insoluble fraction "b" and its slow degradation is typical for maize starch (Table II). Degradation rate of fraction "b" for maize was the lowest for individual particles size. It was ranging from 0.050 (K4) to 0.078%.h^{-1} (K1). Proportion of the soluble fraction was the highest in K1 (45.0%). Decreasing of corn particle size caused increasing of outflow rate from the rumen and effective degradability (Ewing *et al.*, 1986; Rémond *et al.*, 2004). The values of starch effective degradability for individual maize fractions (K1 to K4) were 52.1–76.1% at outflow rate 0.06.h^{-1} and 0,08.h^{-1} was lower in comparison with wheat and barley.

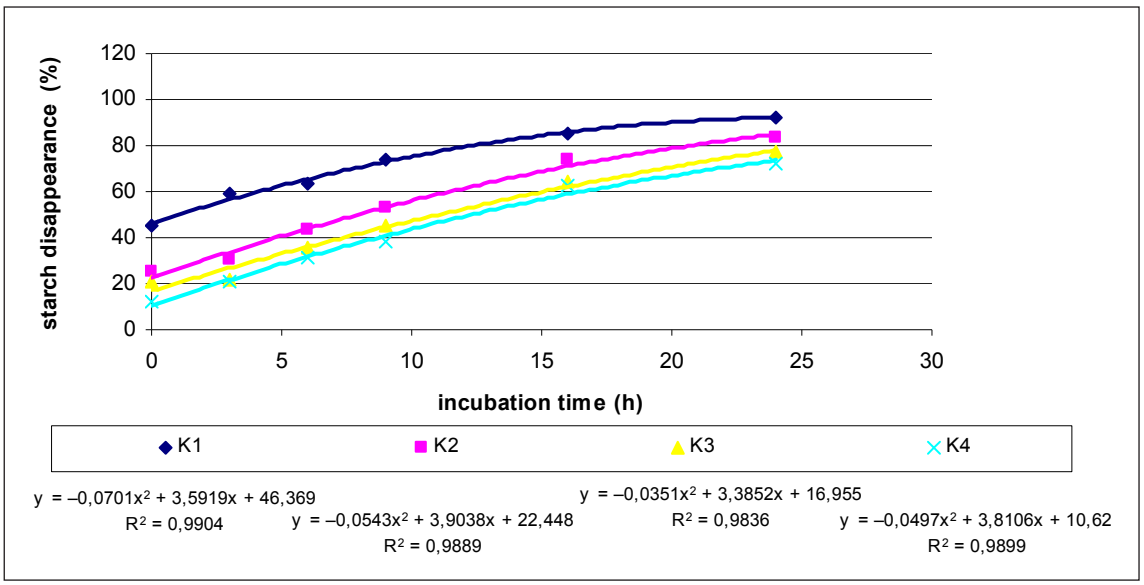
The linear and quadratic dependences of starch disappearance from maize on incubation times and particle size (Fig. 3 and Table V) were significant with very high coefficients of determination (from R^2 = 0.9836^{++} for K3 to R^2 = 0.9904^{++} for K1).

Herrera – Saldana *et al.* (1990) observed starch EDg of five grains ground to pass a 1 mm sieve. Effective starch degradability was 61.9% for maize, 94.8% for wheat and 90.2% for barley. Our EDg results for particle size < 1.4 mm (P1, J1) are comparable with data published for wheat and barley, but we have determined higher value for maize (76.1%).

V: *Summary of linear (L) and quadratic (Q) functions of starch disappearance from maize influenced by incubation time and particle size*

Fraction n=6	function	a	b	c	R^2	R^2_α
K1	L	51.6330	1.8898		0.9297	++
	Q	46.3690	3.5919	–0.0701	0.9904	++
K2	L	26.5210	2.5865		0.9687	++
	Q	22.4480	3.9038	–0.0543	0.9889	++
K3	L	19.5870	2.5338		0.9748	++
	Q	16.9550	3.3852	–0.0351	0.9836	++
K4	L	14.3470	2.6053		0.9732	++
	Q	10.6200	3.8106	–0.0497	0.9899	++

$^{+}P<0.05$; $^{++}P<0.01$
$R_{0.05}(1.4) = 0.8110$ $R^2_{0.05}(1.4) = 0.6577$; $R_{0.01}(1.4) = 0.9170$ $R^2_{0.01}(1.4) = 0.8408$
$R_{0.05}(2.3) = 0.9300$ $R^2_{0.05}(2.3) = 0.8649$; $R_{0.01}(2.3) = 0.9770$ $R^2_{0.01}(2.3) = 0.9545$



3: *Quadratic relationship of starch disappearance between incubation time and particle size of maize*

SÚHRN

Efekt mechanickej úpravy zrnín na bachorovú degradovateľnosť škrobu

Hoci škrob v obilných zrnách je takmer kompletne trávený v celom tráviacom trakte, rýchlosť a rozsah bachorovej degradácie závisia od druhu zrna a spôsobu úpravy. Cieľom práce bolo určiť efekt veľkosti častíc (≤ 1,4, 1,5–2,5, 2,6–3,0 a > 3,0 mm) mechanicky upravenej pšenice, jačmeňa a kukurice na bachorovú degradáciu škrobu. Na určenie degradácie škrobu sme použili štandardizovanú *in sacco*

metódu s inkubáciami v trvaní 0, 3, 6, 9, 16, 24 hodín a pre kukuricu aj 48 hodín. Zistili sme preukazné rozdiely v efektívnej degradovateľnosti škrobu medzi experimentálnymi krmivami ako aj v závislosti od veľkosti častíc krmív. Pšenica mala najvyššiu efektívnu degradovateľnosť škrobu (83,0–95,2 %), a najnižšia bola v kukurici (52,1–76,1 %). Redukciou veľkosti častíc sa degradovateľnosť škrobu zvyšovala vo všetkých krmivách. Efektívna degradovateľnosť škrobu bola najvyššia v najmenších časticiach (≤ 1.4mm), 95,2 pre pšenicu, 91,2 pre jačmeň a 76,1 % pre kukuricu. Tieto výsledky poukazujú na to, že výhodnejšou úpravou je hrubé šrotovanie, pretože väčšie častice majú nižšiu bachorovú degradovateľnosť a zvyšuje sa pasáž škrobu do duodena.

zrniny, úprava zrnín, škrob, *in sacco* degradovateľnosť

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