

DIGESTION OF CARBOHYDRATES IN FIBRE-RICH DIETS FOR PIGS

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KOKKUVÕTE: Süsivesikute seeduvus kiudainerikastes sigade söötades. Katsesse valiti neli ristandorikat (L×Y) kelle kehamaas katse algul oli keskmiselt 28 kg ja katse lõpul 67 kg. Sead olid peensoole seeduvuse määramiseks varustatud vastavate fistulitega. Sigadele söödeti nelja erinevat katsesööta järgides 4×4 ladina ruudu skeemi. Katsesöödad koosnesid odraajahust, millele oli lisatud kas 0, 5, 10 või 20% lutserni lehejahu (LLJ). Kõikidele katsesöötadele oli lisatud 4% vitamiinide ja mineraalide segu ning 0,5% inertainet (Cr₂O₃). Iga katseperiood kestis 15 päeva, mis oli jaotatud eelperioodiks (10 päeva) ja arvestusperioodiks (5 päeva). LLJ osatähtsuse suurenemisega katsesöötades suurenes oluliselt ka ratsioonikiu, ligniini, mannoosi, galaktoosi, glükoosi ja uroonhapete söömus, kuid oluliselt vähenes tärklise, arabinoosi ja ksüloosi söömus. Katsesöödade LLJ osatähtsuse suurenemisega vähenes ratsioonikiu seeduvus peensooles. Ratsioonikiu seeduvus kogu seedekanalil vähenes aga ainult söödas, millele oli lisatud 20% LLJ. Neutraalsuhkrute seeduvus seedekanalil erinevates osades sarnanes ratsioonikiu seeduvusega. Uroonhapete seeduvus kogu seedekanalil suurenes (P<0.05) proportsionaalselt sööda LLJ osatähtsuse suurenemisega. Ratsioonikiu proportsionaalne seeduvus (protsentuaalne osatähtsus kogu seeduvusest) sigade jämesooles oli 33%, 46%, 48% ja 62% olenevalt sellest, kas söödale oli lisatud 0, 5, 10 või 20% lutserni lehejahu. Ka kõikide neutraalsuhkrute proportsionaalne seeduvus jämesooles suurenes, mis viitab kiudaine komponentide mikrobiaalse lõhustuvuse suurenemisele sigade jämesooles.

Abstract

The experiment was carried out on four crossbred (Landrace × Yorkshire) castrated male pigs with an average live weight of 28 kg at the start and 67 kg at the end of the experiment. All pigs were fitted with postvalvular t-caecal (PVTC) cannulas at the terminal ileum for determination of ileal digestibility. Four experimental diets with increasing level of lucerne leaf meal (LLM) were fed according to a 4×4 Latin Square design. The diets were based on barley, which was substituted by 0, 5, 10 or 20% LLM. For ileal digestibility determination, chromium oxide (Cr₂O₃) was included in the diet. The experiment lasted 15 days, which included a pre-experimental period of 10 days and a collection period of 5 days. With increasing inclusion of LLM there was a significant increase in the intake of dietary fibre (DF), Klason lignin, mannose, galactose, glucose and uronic acid residues. In contrast the daily intake of starch, arabinose and xylose residues decreased significantly (P<0.05). Increased LLM inclusion in the diets reduced apparent ileal and total tract digestibility of DM, OM, CP and EE compared with the barley-based diet. The ileal digestibility of total dietary fibre decreased with increasing LLM inclusion, while total tract digestibility of DF was affected only at 20% inclusion of LLM. The ileal and total tract digestibility of neutral sugars (NS) followed the same pattern as the digestion of DF. There was a significant increase in the total tract digestibility of uronic acid (UA) when inclusion of LLM was increasing in the diets. The proportion (% of total tract digestibility) of total DF digested in the hindgut was 33% in the barley-based diet and increased to 46%, 48% and 62% with dietary inclusions of 5, 10 and 20% LLM, respectively. Also, the proportion of all NS components digested in the hindgut increased with LLM inclusion, which shows that microbial breakdown of fibrous components increased in the hindgut.

Keywords: lucerne leaf meal, dietary fibre, ileal digestibility, total tract digestibility.

Introduction

In recent years there has been increased interest for using fibre-rich feedstuffs (forages and various by-products) in modern pig production. Plants can be used as potential protein and energy sources in pig diets and fibres are also associated with improving satiety and well being of pigs. Plant polysaccharides, starch and non-starch polysaccharides (NSP) are the most important energy sources when feeding pigs and other monogastric animals.

Apparent digestibility of nutrients in diets, where cereals have been substituted for bran, oatmeal by-product, forages and other similar foodstuffs rich in structural polysaccharides, has been decreased. Bach

Knudsen et al. (1993) reported that oat bran, because of the cell walls trapping nutrients, reduced the digestibility of oat protein and fat in the small intestine while there was no effect on the digestibility of starch. Kass et al. (1980) investigated the digestion of diets containing 0, 200, 400 or 600 g/kg alfalfa meal in growing pigs. Increasing depression of digestibility of dry matter, nitrogen and cell wall components in the small intestine and in the hindgut, was found as the level of alfalfa in the diet rose.

Lucerne is one of the most important forage crops and is appreciated for its high protein content. It is known that in general the feeding value of lucerne, as well as other forage crops decreases as the plant matures. This has been assigned to various factors such as increasing stem and leaf ratio, decreasing amount of crude protein, increasing amount of cell walls, and increasing lignification of the crop (Nordkvist and Åman, 1986).

Lucerne leaf meal, with its high content of crude protein, minerals and also relatively low content of fibre compared with whole crop, might be an interesting feedstuff for pigs. Kuan et al. (1983) reported that increasing proportion of cell wall material from lucerne leaf meal (LLM) in the diet resulted a linear decrease in the digestibility of dry matter, crude protein and crude fat. Some of the factors responsible for these decreased nutrient digestibility are high lignin content in the diet and the inability of pigs to digest this fraction. Also, increased secretion of metabolic nitrogen, which has been shown to be related to the level of fibre in the diet and increase in the rate of passage (Kuan et al., 1983). The amount and composition of the cell walls are probably the most important factors in determining the nutritive value of the LLM. A few detailed studies of the composition of the LLM cell wall polysaccharides in relation to digestibility have been published.

As a continuation of available information on LLM in pig diets (Lindberg and Cortova, 1995; Lindberg et al., 1995; Reverter and Lindberg, 1998), the purpose of the present paper was to provide information on the ileal and total tract digestibility of dietary carbohydrates in growing pigs given a barley-based diet with increasing inclusion levels of LLM.

Materials and methods

Animals and housing

The experiment was carried out on four crossbred (Landrace × Yorkshire) castrated male pigs with an average live weight of 28 kg (SD 4.6) at the start and 67 kg (SD 8.9) at the end of the experiment. All pigs were surgically fitted with postvalvular t-caecal (PVTC) cannulas (Leeuwen et al., 1991) at the terminal ileum for determination of ileal digestibility.

The animals were housed individually in pens during the pre-experimental periods and were kept in metabolic cages during the collection periods. The rooms had a controlled temperature (20 °C) and the light regime was 07.30–18.00 h.

Experimental design, diets and feeding

Four experimental diets with increasing level of lucerne leaf meal were fed according to a 4×4 Latin Square design. The experiment lasted 15 days, which included a pre-experimental period of 10 days and a collection period of 5 days.

The lucerne crop was harvested at the pre-flowering stage in early June. The crop was pre-dried in the field, baled and barn dried. After drying, the leaves were mechanically separated from the stems. The leaf fraction included a limited amount of residual stems. The material was ground in a hammer mill (3-mm screen) to obtain lucerne leaf meal before it was mixed with the other dietary ingredients. The diets were based on barley, which was substituted by 0, 5, 10 or 20% LLM. For ileal digestibility determination, chromium oxide (Cr₂O₃) was included in the diet (0.5 kg per 100 kg diet fresh weight). All diets were pelleted. The chemical composition of LLM and the diets are given in Table 1.

The pigs were fed two times per day (08.00 and 16.00 h.) with water available *ad libitum*. The daily feed allowance was 4% of the body weight throughout the experiment.

Collection of faeces and urine

Faeces and urine were collected twice daily. Immediately after each collection, the faeces were frozen and kept at -20 °C until analysis. Prior to analysis the faeces were thawed, homogenised in a food processor, divided into smaller samples and freeze dried. The urine was preserved by adding 50 ml 5% H₂SO₄ to the collection jar and stored at +4 °C. After experimental period an aliquot was sampled and frozen at -20 °C.

Ileal digesta were collected on days 3 and 5 of the collection period. A total of 12 samples were collected for each pig and period together covering every second hour for a 24-h period. On each collection day 6 samples were collected, with a one-h adjustment of the time schedule between collection days, to cover every second hour for a 24-h period. Each collection lasted for 1 h during which the whole digesta flow was collected. Ileal digesta samples were kept on ice during the collections and were then frozen immediately. The digesta samples were kept at -20°C until analysed. Prior to analysis the samples were thawed, pooled, homogenised, divided into smaller samples and freeze-dried. Ileal digesta flow was estimated assuming a complete recovery of chromium oxide at the terminal ileum.

Table 1. Dietary ingredients and chemical composition of the diets
Tabel 1. Katsesöötade koostisosad ja keemiline koostis

Item <i>Näitaja</i>	LLM <i>LLJ</i>	Lucerne leaf meal inclusion % <i>Lutserni lehejahu osatähtsus %</i>			
		0	5	10	20
<i>Ingredients / Koostisosad:</i>					
Barley, g/kg <i>Oder, g/kg</i>		955	905	855	755
Lucerne leaf meal, g/kg <i>Lutserni lehejahu, g/kg</i>		0	50	100	200
Vitamins and minerals, g/kg <i>Vitamiinid ja mineraalid, g/kg</i>		40	40	40	40
Cr ₂ O ₃ , g/kg		5	5	5	5
<i>Chemical composition:</i>					
<i>Keemiline koostis:</i>					
Crude protein, % / <i>Toorproteiin, %</i>	23.4	12.1	12.4	12.8	13.8
Crude fat, % / <i>Toorrasv, %</i>	2.9	2.9	2.8	3.0	3.4
Sugars, % / <i>Suhkrud, %</i>	6.6	2.5	2.6	2.9	3.2
Starch, % / <i>Tärklis, %</i>	3.2	47.8	45.0	43.0	39.0
Dietary fibre, % / <i>Ratsioonikiud, %</i>	30.6	18.0	18.0	19.1	19.9
Neutral sugars, %:	17.2	16.0	15.3	15.8	15.7
<i>Neutraalsuhkrud, %:</i>					
Rhamnose, % / <i>Ramnoos, %</i>	0.39	–	0.04	0.05	0.09
Fucose, % / <i>Fukoos, %</i>	0.09	–	–	–	–
Arabinose, % / <i>Arabinoos, %</i>	2.04	2.23	2.02	2.05	2.03
Xylose, % / <i>Ksilooos, %</i>	2.18	4.59	4.06	4.13	3.82
Mannose, % / <i>Mannoos, %</i>	0.96	0.34	0.34	0.40	0.42
Galactose, % / <i>Galaktoos, %</i>	1.75	0.27	0.33	0.42	0.59
Glucose, % / <i>Gliukoos, %</i>	9.80	8.59	8.46	8.70	8.77
Klason lignin, % / <i>Ligniin, %</i>	4.0	1.5	1.8	1.9	2.0
Uronic acid, % / <i>Uroonhapped, %</i>	9.3	0.5	0.9	1.4	2.2
Ash, % / <i>Toortuhk, %</i>	10.7	5.1	5.3	5.7	6.4

Chemical analysis

All feed, digesta and faecal analyses were performed on freeze-dried samples. The samples were all milled through a 1-mm screen with a Wiley mill prior to analysis.

Dry matter and ash were determined as described by Jennische and Larsson (1990). Crude protein content (total N×6.25) was determined with a conventional macro-Kjeldahl method and crude fat was determined according to Larsson (1989). Starch was analysed enzymatically according to Larsson and Bengtsson (1983). Dietary fibre (defined as the sum of non-starch polysaccharide residues, amylase-resistant starch and Klason lignin) was determined according to a gas chromatographic-colorimetric-gravimetric method (Theander et al, 1995). After selective removal of starch in acetate buffer using a thermostable α -amylase and an amyloglucosidase, soluble dietary fibre components were precipitated with 80% ethanol and then the non-starch polysaccharides were hydrolysed with sulphuric acid. Neutral monosaccharides in the acid hydrolysis were determined as alditol acetates by gas chromatography. Uronic acids in the acid hydrolysis were determined by colorimetry, and Klason lignin (sulphuric acid lignin) calculated gravimetrically as the ash-free acid insoluble residue. All analyses of dietary fibre were run in at least duplicate and the results are reported on a dry matter basis.

Chromium in feed and ileal digesta were determined with emission spectrophotometry on diluted samples in phosphoric acid (85%).

Statistical analysis

Analysis of variance was performed according to a Latin-square design (Patterson and Lucas, 1962) using the GLM procedure. Results are presented as least square means with their standard error.

Results

Feed intake

Dry matter (DM) and organic matter (OM) intakes were similar across the diets (Table 2). There was a significant increase in the daily intake of crude protein (CP), crude fat (EE) and dietary fibre (DF) with

increasing content of LLM. The daily intake of starch decreased with increasing level of LLM and neutral sugar (NS) intake was affected when LLM was included in the diet. With increasing inclusion of LLM there was a significant increase in the intake of Klason lignin, mannose, galactose, glucose and uronic acid residues. In contrast the daily intake of arabinose and xylose residues decreased significantly ($P < 0.05$).

Table 2. Mean daily intake of nutrients

Tabel 2. Toitainete söömus

Item Näitaja	Lucerne leaf meal inclusion % <i>Lutserni lehejahu osatähtsus %</i>				SEM
	0	5	10	20	
Dry matter, g/day <i>Kuivaine, g/päevas</i>	1318	1328	1327	1329	3.1
Organic matter g/day <i>Orgaaniline aine, g/päevas</i>	1251	1257	1251	1244	2.8
Crude protein g/day <i>Toorproteiin, g/päevas</i>	159 ^a	164 ^b	170 ^c	183 ^d	1.2
Crude fat g/day <i>Toorrasv, g/päevas</i>	39 ^a	37 ^a	40 ^b	45 ^c	0.4
Starch g/day <i>Tärklis, g/päevas</i>	630 ^a	597 ^b	570 ^c	518 ^d	3.7
Dietary fibre g/day <i>Ratsioonikiud, g/päevas</i>	237.6 ^a	239.3 ^a	253.6 ^b	265.2 ^c	1.7
Neutral sugars, g/day: <i>Neutraalsuhkrud, g/päevas:</i>	211.2 ^a	202.5 ^b	209.2 ^c	208.9 ^c	0.4
Rhamnose, g/day <i>Ramnoos, g/päevas</i>	–	0.6	0.7	1.2	0.04
Fucose, g/day <i>Fukoos, g/päevas</i>	–	–	–	–	–
Arabinose, g/day <i>Arabinoos, g/päevas</i>	29.4 ^a	26.9 ^b	27.3 ^c	27.0 ^{bc}	0.09
Xylose, g/day <i>Ksüloos, g/päevas</i>	60.5 ^a	53.9 ^b	54.9 ^b	50.8 ^c	0.3
Mannose, g/day <i>Mannoos, g/päevas</i>	4.4 ^a	4.6 ^a	5.4 ^b	5.6 ^b	0.06
Galactose, g/day <i>Galaktoos, g/päevas</i>	3.5 ^a	4.3 ^b	5.6 ^c	7.8 ^d	0.2
Glucose, g/day <i>Gliikoos, g/päevas</i>	113.3 ^a	112.4 ^a	115.5 ^b	116.5 ^b	0.4
Klason lignin, g/day <i>Ligniin, g/päevas</i>	19.8 ^a	24.2 ^b	25.7 ^c	26.8 ^c	0.3
Uronic acid, g/day <i>Uroonhapped, g/päevas</i>	6.5 ^a	12.4 ^b	18.7 ^c	29.6 ^d	1.0

^{a,b,c,d} – Mean values with different superscripts in the same row are significantly different ($P < 0.05$)

^{a,b,c,d} – Erinevate tähtedega märgitud näitajad erinevad üksteisest oluliselt ($P < 0.05$)

Ileal and total tract flow

There was a significant increase in the ileal and total tract flow of nutrients with increasing inclusion of LLM (Table 3). The ileal flow of starch was small and not affected by LLM inclusion, and the total tract flow of starch was negligible. There was a more pronounced effect of LLM on the ileal flow of DM, OM and DF than on the total tract flow.

The daily ileal flow of all dietary fibre components (excluding xylose residues) was increased when the inclusion of LLM was increased in the diets. The total tract flow of total dietary fibre, as well as rhamnose, mannose, galactose residues and Klason lignin, was increased significantly only at the highest inclusion level of LLM, while the daily total tract flow of arabinose and xylose was significantly reduced. There was a significant increase in the total tract flow of uronic acid with increasing inclusion of LLM. The effect of increased level of LLM on the total tract flow of total neutral sugar residues was not significant.

Table 3. Daily ileal and total tract flow of nutrients
Tabel 3. Toitainete voog seedekanalali erinevates osades

Item <i>Näitaja</i>	Lucerne leaf meal inclusion % <i>Lutserni lehejahu osatähtsus %</i>				SEM
	0	5	10	20	
Ileal / <i>Iileumis</i>					
Dry matter, g/day / <i>Kuivaine, g/päevas</i>	368 ^a	413 ^b	438 ^b	507 ^c	12.8
Organic matter g/day / <i>Orgaaniline aine, g/päevas</i>	318 ^a	355 ^b	376 ^b	433 ^c	11.5
Crude protein g/day / <i>Toorproteiin, g/päevas</i>	47 ^a	50 ^a	54 ^a	62 ^b	2.6
Crude fat g/day / <i>Toorrasv, g/päevas</i>	12 ^a	14 ^b	14 ^b	17 ^c	0.5
Starch g/day / <i>Tärklis, g/päevas</i>	8	11	11	13	2.3
Dietary fibre g/day / <i>Ratsioonikiud, g/päevas</i>	151.4 ^a	170.2 ^{ab}	181.6 ^b	216.0 ^c	7.3
Neutral sugars, g/day:	125.3 ^a	134.2 ^a	141.9 ^{ab}	158.7 ^b	6.2
<i>Neutraalsuhkrud, g/päevas:</i>					
Rhamnose, g/day / <i>Ramnoos, g/päevas</i>	0.5 ^a	0.7 ^{ab}	0.9 ^b	1.4 ^c	0.07
Fucose, g/day / <i>Fukoos, g/päevas</i>	0.2 ^a	0.3 ^a	0.4 ^a	0.7 ^b	0.07
Arabinose, g/day / <i>Arabinoos, g/päevas</i>	18.8 ^a	19.9 ^{ab}	20.6 ^{ab}	22.4 ^b	0.8
Xylose, g/day / <i>Ksüloos, g/päevas</i>	42.2	44.3	43.6	44.8	1.5
Mannose, g/day / <i>Mannoos, g/päevas</i>	2.7 ^a	3.3 ^b	3.8 ^b	4.6 ^c	0.2
Galactose, g/day / <i>Galaktoos, g/päevas</i>	3.6 ^a	4.3 ^a	5.1 ^b	6.8 ^c	0.2
Glucose, g/day / <i>Gliukoos, g/päevas</i>	57.4 ^a	61.5 ^a	67.6 ^{ab}	78.2 ^b	3.8
Klason lignin, g/day / <i>Ligniin, g/päevas</i>	21.2 ^a	26.6 ^b	26.4 ^b	34.9 ^c	0.9
Uronic acid, g/day / <i>Uroonhapped, g/päevas</i>	4.8 ^a	9.4 ^b	13.3 ^c	22.3 ^d	0.7
Total tract / <i>Kogu seedekanal</i>					
Dry matter, g/day / <i>Kuivaine, g/päevas</i>	238 ^a	232 ^a	251 ^a	289 ^b	7.5
Organic matter g/day / <i>Orgaaniline aine, g/päevas</i>	191 ^a	186 ^a	201 ^a	231 ^b	6.3
Crude protein g/day / <i>Toorproteiin, g/päevas</i>	36 ^a	37 ^a	39 ^a	48 ^b	1.5
Crude fat g/day / <i>Toorrasv, g/päevas</i>	15 ^a	17 ^a	16 ^a	20 ^b	0.9
Starch g/day / <i>Tärklis, g/päevas</i>	<1	<1	<1	<1	0.1
Dietary fibre g/day / <i>Ratsioonikiud, g/päevas</i>	112.7 ^a	109.4 ^a	113.5 ^a	129.9 ^b	3.2
Neutral sugars, g/day:	81.7	77.4	77.3	84.0	2.1
<i>Neutraalsuhkrud, g/päevas:</i>					
Rhamnose, g/day / <i>Ramnoos, g/päevas</i>	0.6 ^a	0.7 ^a	0.7 ^a	0.9 ^b	0.05
Fucose, g/day / <i>Fukoos, g/päevas</i>	0.2	0.2	0.2	0.2	0.03
Arabinose, g/day / <i>Arabinoos, g/päevas</i>	10.1 ^a	9.4 ^{ab}	9.1 ^b	9.1 ^b	0.2
Xylose, g/day / <i>Ksüloos, g/päevas</i>	30.1 ^a	28.0 ^{ab}	27.4 ^b	28.3 ^{ab}	0.7
Mannose, g/day / <i>Mannoos, g/päevas</i>	1.0 ^a	1.1 ^a	1.2 ^a	1.5 ^b	0.07
Galactose, g/day / <i>Galaktoos, g/päevas</i>	2.2 ^a	2.1 ^a	2.1 ^a	2.7 ^b	0.1
Glucose, g/day / <i>Gliukoos, g/päevas</i>	37.6 ^{ab}	35.9 ^a	36.7 ^a	41.4 ^b	1.1
Klason lignin, g/day / <i>Ligniin, g/päevas</i>	27.5 ^a	28.4 ^a	31.7 ^a	40.0 ^b	1.3
Uronic acid, g/day / <i>Uroonhapped, g/päevas</i>	3.5 ^a	3.8 ^a	4.5 ^b	5.9 ^c	0.2

^{a,b,c,d} – Mean values with different superscripts in the same row are significantly different ($P < 0.05$)

^{a,b,c,d} – Erinevate tähtedega märgitud näitajad erinevad üksteisest oluliselt ($P < 0.05$)

Ileal and total tract digestibility

The digestibility of DM and OM was significantly reduced with increasing inclusion levels of LLM (Table 4). The ileal digestibility of EE was reduced with LLM inclusion, while the total tract EE digestion was not significantly affected by the diet. The total tract digestibility of CP was significantly reduced at the highest inclusion level of LLM in the diet. Starch digestibility was unaffected and was completely digested in all diets.

The ileal digestibility of total DF decreased with increasing LLM inclusion, while total tract digestibility of DF was affected only at 20% inclusion of LLM. The ileal and total tract digestibility of neutral sugars (NS) followed the same pattern as the digestion of DF. There was a significant increase in the total tract digestibility of uronic acid (UA) when inclusion of LLM was increasing in the diets. Negative values were found in both the ileal and total tract digestibility of Klason lignin and rhamnose.

In the present experiment, the proportion of all NS components and total DF digested in the hindgut (Figure 1) was increased when increasing the inclusion of LLM in the diet.

Table 4. Ileal and total tract digestibility of nutrients
Tabel 4. Toitainete seeduvus seedekanalil erinevates osades

Item <i>Näitaja</i>	Lucerne leaf meal inclusion % <i>Lutserni lehejahu osatähtsus %</i>				SEM
	0	5	10	20	
Ileal / <i>Iileumis</i>					
Dry matter, % / <i>Kuivaine, %</i>	72 ^a	69 ^b	67 ^b	62 ^c	0.9
Organic matter, % / <i>Orgaaniline aine, %</i>	74 ^a	72 ^{ab}	70 ^b	65 ^c	0.8
Crude protein, % / <i>Toorproteiin, %</i>	69	70	68	66	1.7
Crude fat, % / <i>Toorrasv, %</i>	69 ^a	63 ^b	63 ^b	62 ^b	0.9
Starch, % / <i>Tärklis, %</i>	98	98	98	98	0.3
Dietary fibre, % / <i>Ratsioonikiud, %</i>	35.6 ^a	29.2 ^a	29.4 ^a	19.4 ^b	2.7
Neutral sugars, %:	40.0 ^a	34.1 ^{ab}	33.2 ^{ab}	24.9 ^b	2.7
<i>Neutraalsuhkrud, %:</i>					
Arabinose, % / <i>Arabiin, %</i>	35.5 ^a	26.2 ^{ab}	25.7 ^{ab}	18.5 ^b	2.9
Xylose, % / <i>Ksüloos, %</i>	29.9 ^a	18.3 ^b	21.6 ^{ab}	12.5 ^b	2.8
Mannose, % / <i>Mann, %</i>	39.3 ^a	29.0 ^b	30.2 ^{ab}	17.8 ^c	2.9
Galactose, % / <i>Galaktoos, %</i>	-2.2 ^a	0.0 ^{ac}	8.9 ^{bc}	13.9 ^b	3.0
Glucose, % / <i>Gliikoos, %</i>	48.5 ^a	45.7 ^a	42.5 ^{ab}	33.8 ^b	2.9
Klason lignin, % / <i>Ligniin, %</i>	-8.7 ^a	-9.4 ^a	-1.6 ^a	-28.9 ^b	4.9
Uronic acid, % / <i>Uroonhapped, %</i>	26.8	25.0	28.8	24.7	2.7
Total tract / <i>Kogu seedekanalil</i>					
Dry matter, % / <i>Kuivaine, %</i>	82 ^a	82 ^a	81 ^a	78 ^b	0.6
Organic matter, % / <i>Orgaaniline aine, %</i>	85 ^a	85 ^a	84 ^a	81 ^b	0.5
Crude protein, % / <i>Toorproteiin, %</i>	77	77	77	74	0.9
Crude fat, % / <i>Toorrasv, %</i>	61	54	58	55	2.6
Starch, % / <i>Tärklis, %</i>	100	100	100	100	0.1
Dietary fibre, % / <i>Ratsioonikiud, %</i>	53.0	54.5	56.1	51.2	1.4
Neutral sugars, %:	61.7 ^{ab}	61.8 ^{ab}	63.8 ^b	59.9 ^a	1.0
<i>Neutraalsuhkrud, %:</i>					
Arabinose, % / <i>Arabiin, %</i>	65.9	65.1	67.4	66.5	0.8
Xylose, % / <i>Ksüloos, %</i>	50.7 ^a	47.9 ^{ab}	51.1 ^a	44.5 ^b	1.2
Mannose, % / <i>Mann, %</i>	77.8 ^a	76.9 ^{ab}	78.6 ^a	73.0 ^b	1.2
Galactose, % / <i>Galaktoos, %</i>	39.0 ^a	51.6 ^b	63.3 ^c	66.2 ^c	2.1
Glucose, % / <i>Gliikoos, %</i>	67.1 ^{ab}	68.1 ^a	68.8 ^a	64.5 ^b	1.0
Klason lignin, % / <i>Ligniin, %</i>	-37.9 ^a	-15.2 ^b	-21.9 ^{ab}	-48.3 ^a	6.0
Uronic acid, % / <i>Uroonhapped, %</i>	48.2 ^a	69.9 ^b	76.5 ^{bc}	79.9 ^c	2.0

^{a,b,c,d} – mean values with different superscripts in the same row are significantly different ($P < 0.05$)

^{a,b,c,d} – erinevate tähtedega märgitud näitajad erinevad üksteisest oluliselt ($P < 0.05$)

Discussion

The chemical composition of barley used here agreed well with earlier data (Oscarsson et al., 1996; Fadel et al., 1988; Pettersson, 1996). Also, the dietary fibre composition of barley used here agreed well with earlier reported values for hulled barley (Oscarsson et al., 1996; Fadel et al., 1988), where rhamnose and fucose residues were found in small amounts (<0.1% of DM) or were not reported. In here Klason lignin, mannose, galactose and uronic acids were found in small amounts in the barley, whereas rhamnose and fucose residues were not found. The three major dietary fibre monosaccharides in the barley were glucose, arabinose and xylose (Table 1).

The LLM was characterised by a high content of DF, CP and ash, and a low content of fat and starch. The chemical composition of LLM agreed well with values reported by Kuan and Stanogias (1983). The high value of UA in LLM agreed with published values for legumes and shows together with arabinose, galactose and rhamnose residues that LLM has a high content of pectins. The Klason lignin content of LLM used here was low compared with the whole crop and was similar to that reported by others (Christian et al., 1970).

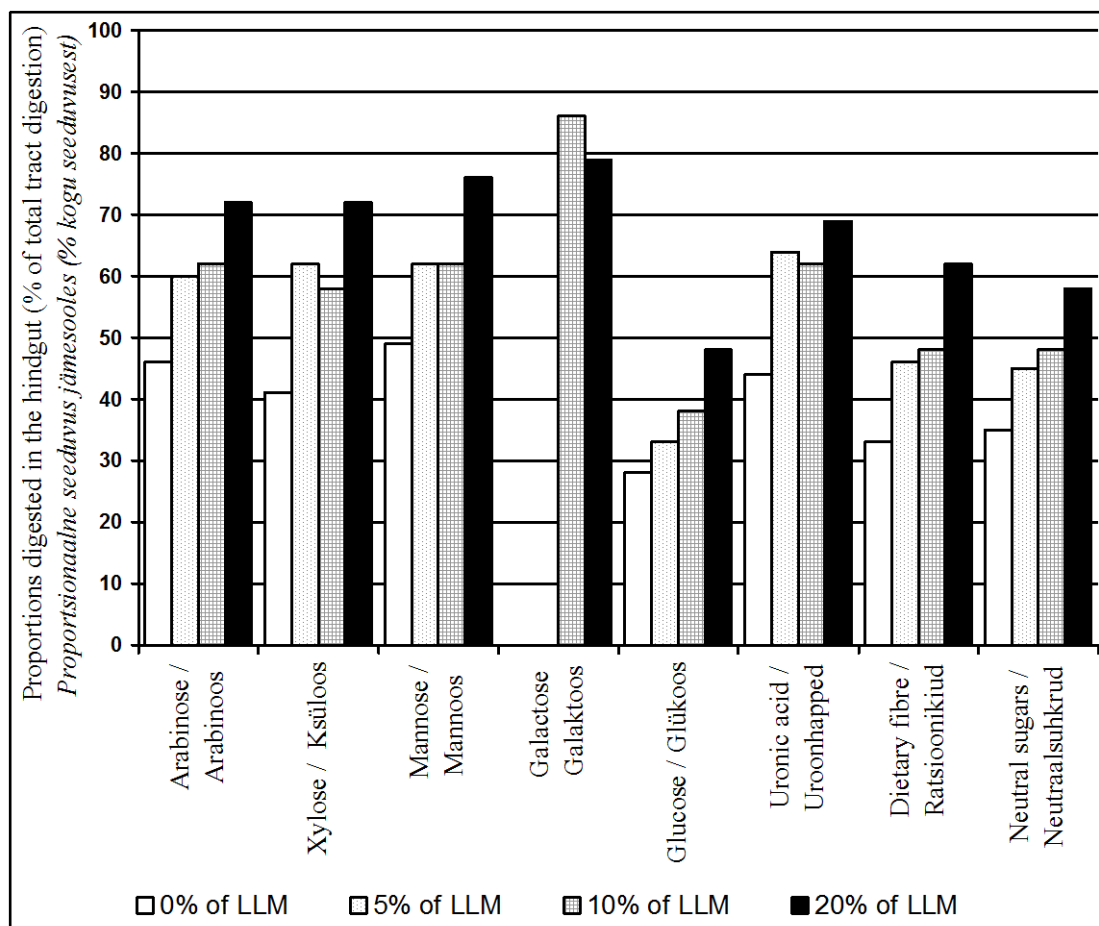


Figure 1. The proportions (% of total tract digestion) of dietary fibre components digested in the hindgut of pigs **Joonis 1.** Ratsioonikiu ja selle komponentide proportsionaalne seeduvus (protsentuaalne osatähtsus kogu seeduvusest) sigade jämesooles

Increased LLM inclusion in the diets reduced apparent ileal and total tract digestibility of DM, OM, CP and EE compared with the barley-based diet. Similar effects have also been reported when forage meals were included in cereal-based diets for pigs (Andersson, 1997; Kuan et al, 1983; Stanogias and Pearce, 1985). The depressing effect on ileal and total tract digestibility of nutrients was most pronounced at the highest inclusion level of LLM. The reduction in apparent digestibility can mainly be attributed to the differences in chemical composition between the barley-based diet and the LLM (Lindberg et al, 1995). Also, an increased rate of passage has been implicated as a factor affecting nutrient digestibility (Kass et al, 1980).

Higher ileal digestion of EE compared with the total tract digestion in all diets can be explained by increased production of microbial fatty acids in the hindgut.

Starch from all diets was almost completely digested (98%) at the end of the small intestine and was not affected by LLM inclusion. Insoluble DF and soluble DF do not affect starch digestibility in the small intestine of pigs (Bach Knudsen and Hansen, 1991).

Ileal and faecal polysaccharides were determined with no previous fractionation and it is not known whether the sugars detected represent dietary fibre residues, bacterial cell-wall polysaccharides or endogenous polysaccharides. However, most of the sugars excreted in faeces may originate from the fibre (Nyman and Asp, 1985).

The total tract digestibility of DF was similar in all diets and was not significantly affected by the LLM inclusion. Our data suggest that a significant degradation of some dietary fibres can occur before the small intestine in pigs. Except for rhamnose residues in the diets, all NSP residues were digested significantly before the terminal ileum. This was most likely due to microbial activity in the small intestine (Chesson et al., 1985; Drochner, 1991).

Here, ileal digestibility of all sugars (excluding galactose) was depressed when LLM was included in the diet. The ileal digestibility of DF components was most affected at the highest level of LLM. The highest ileal digestibility was found for glucose residues (34–48%). Since NS glucose residues include β -glucans, the high ileal digestibility of β -glucans probably caused a higher NS glucose degradation relative to other NS residues (Fadel et al., 1988). Graham et al. (1986) found that approximately 70% of barley β -glucans were digested at the

terminal ileum. Cellulolytic and pectinolytic anaerobes are found in the small intestine of pigs fed different diets (Chesson et al., 1985). Thus, some of glucose residues digested at the ileum may have originated from cellulose.

Increased ileal digestibility of galactose could be due to increased content of pectins in the diets. This may be related to the linear poorly branched β -(1-4) structure of the galactose backbone (Carré et al., 1985), which may result in its separate degradation. Biochemical investigations have demonstrated that galactan chains were labile and probably highly susceptible to fermentative breakdown (Carré et al., 1985). Similar results for galactose digestibility were reported by Jørgensen et al. (1996) in pigs fed low and high levels of pectin-fibre diets. In contrast, Champ et al. (1989) found negative ileal digestibility of galactose when feeding wheat bran diet to rats. No significant differences in the digestibility of UA were found in the small intestine of pigs when inclusion of LLM was increased.

In the total tract, mannose disappeared more than the other monosaccharides of the dietary fibre. Mannose residue most likely originated from the gums (glucomannans), which are characterised as soluble carbohydrates, and occur in various vegetables and legumes. High ileal and total tract digestibility of mannose were found also in barley-based pig diets (Fadel et al., 1988). However, the precision of estimation of mannose digestibility is low because only a small amount of this monosaccharide was detected in the diets.

Total tract digestibility of UA and galactose increased significantly when LLM was included in the diet. Similar results were reported also in studies with the whole crop of lucerne (Nordkvist and Åman, 1986)

As previously shown for faecal digestibilities of a cereal-based diet and whole-crop peas in pigs (Graham et al., 1985), xylose residue was the least degradable polysaccharide in both feeds investigated. Also, xylose was generally the least fermentable component of dietary fibre along the whole digestive tract.

Contamination with endogenous and microbial matter could contribute to the polysaccharide content of the digesta and lead to an underestimation of fibre digestion. This could explain some of the negative digestibility found for the polysaccharide constituents. The negative ileal and total tract digestibility for Klason lignin have also been reported earlier (Graham et al., 1986; Fadel et al., 1988). The Klason lignin recovered includes all compounds that are resistant to acid hydrolysis and may have included compounds from carbohydrate-protein transformation reactions formed during the analysis (Theander et al., 1995).

The effect of increasing the inclusion of LLM from 0% to 20% was an increased digestibility of DF in the hindgut. The proportion (% of total tract digestibility) of total DF digested in the hindgut was 33% in the barley-based diet and increased to 46%, 48% and 62% with dietary inclusions of 5, 10 and 20% LLM, respectively. Also, the proportion of all NS components digested in the hindgut increased with LLM inclusion, which shows that microbial breakdown of fibrous components increased in the hindgut. A high digestibility of fibrous components in the large intestine, when forage meal inclusion was increased in the diet has also been reported by others (Andersson, 1997; Lindberg and Cortova, 1995).

In conclusion, increased inclusion of LLM in a barley-based diet significantly reduces the ileal and total tract digestibility of DM and OM. In contrast, no statistical differences were found in total tract digestibility of starch, CP, EE and DF in pigs fed barley and LLM diets.

A significant part of all components of neutral sugars were digested in the small intestine, probably as a result of bacterial activity, and this should facilitate a more complete digestion of other nutrients in the upper part of the tract (Vervaeke et al., 1991). High ileal digestibility of β -glucans resulted in higher glucose degradation relative to other NS residues. The total tract digestibility of most dietary fibre components tended to be similar or depressed at the highest level of LLM inclusion. The increased digestibility of uronic acids and galactose was due to an increased content of LLM in the diet in combination with a high digestibility of pectic components.

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