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# Mineral and Nitrogen Utilization in Rats Fed Diets Containing Various Monosaccharides

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## ABSTRACT

The aim of the present study was to compare the effects of five different dietary monosaccharides on mineral and nitrogen utilization in female rats. The experimental diets contained 9.2% (w/w) of either glucose, xylose, arabinose, galacturonic acid or galactose. A restricted amount of feed was administered daily. After 21 days on the diets, urine and feces were collected separately and quantitatively for 7 days. Urine and feces were analysed for nitrogen, calcium, phosphorus and magnesium and the balances were calculated. Substantial fractions of the ingested xylose, arabinose and galactose groups were recovered in urine. There was no differential effect of the monosaccharides on body-weight gain and carcass composition. Apparent nitrogen absorption was reduced by the feeding of either xylose, arabinose or galacturonic acid when compared with glucose. Dietary galactose did not affect apparent nitrogen absorption. The lowering effect of xylose, arabinose and galacturonic acid may be explained by enhanced bacterial fermentation and increased fecal excretion of bacterial protein. The apparent absorption of magnesium was stimulated by the feeding of xylose, arabinose, galacturonic acid and galactose, when compared with glucose. Apparent calcium absorption was enhanced by xylose only and phosphorus absorption was raised by galacturonic acid only. The diet containing galacturonic acid produced a significant increase in kidney concentrations of calcium when compared with the glucose diet. This study shows that the feeding of xylose, arabinose, galacturonic acid or galactose did not influence body-weight gain and carcass composition, but there were different sugar type effects on apparent nitrogen absorption and mineral metabolism.

**Key words:** Rats, minerals, nitrogen, diet, glucose, xylose, arabinose, galacturonic acid, galactose

## INTRODUCTION

The major carbohydrate sources in feedstuffs of vegetable origin are starches and Non-Starch Polysaccharides (NSP) such as cellulose, hemi-cellulose, pectins, raffinose and stachyose. Poultry diets are commonly fortified with enzymes that can hydrolyse NSP because chickens lack the appropriate digestive enzymes. The hydrolysis of NSP yields the monosaccharides glucose, xylose, arabinose, galactose and galacturonic acid. Little is known about the impact of these monosaccharides on nutrient utilization by poultry (Schutte, 1990; Schutte *et al*., 1991).

In this study, rats were used as animal model to assess the impact of dietary monosaccharides on mineral and nitrogen utilization. The type of carbohydrate in the diet of rats has been shown to influence mineral absorption. The feeding of the disaccharide lactose, which consists of glucose

and galactose has been shown to raise the absorption of magnesium, calcium and phosphorus (Heijnen *et al*., 1993). Dietary galacturonic acid, but not pectin, enhanced apparent magnesium absorption in rats (Alhaidary *et al*., 2010; Mohamed *et al*., 2010). In chickens, up to 20% of the ingested arabinose and xylose may appear in the urine (Schutte *et al*., 1991) and thus does not contribute to generation of metabolic energy. This would imply that high dietary inclusion levels of these pentose sugars will diminish growth and nitrogen utilization.

The present study with weanling female rats aimed at comparing the effects of dietary monosaccharides on mineral and nitrogen utilization. The experimental diets contained a high level (9.2%, w/w) of either glucose, xylose, arabinose, galacturonic acid or galactose. In order to prevent diet differences in feed intake and consequent difficult interpretation of the data, a restricted amount of feed was administered daily. After three weeks on the diets, the balances of calcium, magnesium, phosphorus and nitrogen were determined and the apparent mineral absorption was calculated. At the end of the balance period, the carcass composition and the mineral contents in kidney were analyzed.

## MATERIALS AND METHODS

**Animals, housing and diets:** The feeding trial and subsequent measurements were carried out at King Saud University in the period of September to December, 2009. Female Wistar Hsd/Cpb:WU rats, aged about 3 weeks, were used. On arrival, they were housed in groups of 4 animals in wire-topped, polycarbonate cages (37.5×22.5×15.0 cm) with a layer of sawdust as bedding. A commercial pelleted diet and tap water were supplied *ad libitum*.

After 3 days, all rats received a purified diet containing glucose and demineralized water ad libitum. After another 9 days (day 0 of the experiment), the rats were divided into 5 groups of similar body weight, consisting of 20 animals each. The groups were randomly assigned to the purified diets, including the pre-experimental, glucose-containing diet (Table 1). The diets, which were in powdered form, were stored at 4°C until feeding. The animals had limited access to feed and free access to demineralized water. The rats were fed a restricted amount of feed which, based on earlier experience, was equivalent to about 80% of *ad libitum* intake for the glucose diet. During the first week, the rats were given 7 g $day^{-1}$, during the second week it was 9 g $day^{-1}$ and during the last two weeks the amount feed supplied was 10 g $day^{-1}$. Body weights, feed and water intake were recorded. During the experimental period (days 0-28), the rats were housed individually in metabolism cages (314 $cm^2$×12 cm). The cages were located in a room with controlled lighting (light, 07.00-19.00 h), temperature (19-21°C) and relative humidity (45-55%).

Table 1 shows the compositions of the experimental diets. The glucose-containing diet, which also served as pre-experimental diet, contained 10% (w/w) of a glucose preparation with dry matter content of 92%. The other diets had an identical composition, except that the D-glucose component was replaced by either D-xylose, L-arabinose, galacturonic acid or galactose, all four sugars being in the form of anhydrous monosaccharides.

**Collection of samples:** On day 20 of the experiment, the cage parts below the wire-mesh bottom and the tubes for collection of urine and feces were rinsed with 0.1 M HCl and subsequently with demineralized water. To block bacterial and mould growth, 0.07 mL of a 2% (w/v) sodium-azide solution was added daily to the urine collecting tubes. During days 21 to 28, urine and feces of each animal were collected quantitatively each day. Urine volume, pH and feces wet weight were determined. Urine and feces were then stored at 4°C until sample preparation.

Table 1: Composition of the experimental diets

| | Diet code | | | | |
|---|---|---|---|---|---|
| Item | Glucose | Xylose | Arabinose | Galacturonic acid | Galactose |
| **Ingredients (g/100 g)** | | | | | |
| Base diet[1] | 90.00 | 90.00 | 90.00 | 90.00 | 90.00 |
| Glucose | 10.00 | - | - | - | - |
| Xylose | - | 9.20 | - | - | - |
| Arabinose | - | - | 9.20 | - | - |
| Galacturonic acid | - | - | - | 9.20 | - |
| Galactose | - | - | - | - | 9.20 |
| Water | - | 0.80 | 0.80 | 0.80 | 0.80 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| **Chemical analysis (g/100 g)** | | | | | |
| Dry matter | 91.30 | 91.80 | 91.700 | 90.60 | 91.80 |
| Calcium | 0.430 | 0.42 | 0.430 | 0.42 | 0.42 |
| Magnesium | 0.037 | 0.039 | 0.037 | 0.036 | 0.038 |
| Phosphorus | 0.390 | 0.370 | 0.360 | 0.390 | 0.350 |

[1]The base diet consisted of (g): casein, 15.1; coru oil, 2.5; coconut fat, 2.5; starch, 60.94; cellulose, 3.0; $CaCO_3$, 1.24; $NaH_2PO_4.2H_2O$, 1.51; $MgCO_3$, 0.14; KCl, 0.1; $KHCO_8$ 0.77; mineral premix, 1.0; vitamin premix, 1.2. The vitamin premix consisted of the following (mg): thiamin, 0.4; riboflavin, 0.3; niacinamide, 2; D.L-calcium panthothenate (purity 45%), 1.78; pyridoxine, 0.6; cyanocobalamine (purity 0.1%), 5; choline chloride (purity 50%), 200; folic acid, 0.1; biotin, 0.2; menadione, 0.005; D,L-alpha tocopheryl acetate (purity 50%), 6; retinyl acetate and retinyl palmitate, 0.8 (120 retinol eqnivalents); cholecalciferol, 0.2 (100 IU); corn meal, 982.615. The mineral premix consisted of the following (mg): $MnO_2$, 7.9; $FeSO_4.7H_2O$, 17.4; $ZnSO_4.H_2O$, 3.3; $NiSO_4.6H_2O$, 1.3; $CuSO_4.5H_2O$, 1.57; NaF, 0.2; $CrCl_3.6H_2O$, 0.15; $SnCl_2.2H_2O$, 0.19; $NH_4VO_3$, 0.02; KI, 0.02; $Na_2SeO_3.5H_2O$, 0.03; coru meal, 967.92

At the end of the experiment (day 28), between 09.00 and 12.00 h, the non-fasted rats were anaesthetized with diethyl ether and were killed by cervical dislocation. The right kidney was removed and weighed after discarding the capsule. Then, the kidney was frozen at -20°C until chemical analysis. Liver and cecum, including its contents, were also removed and weighed immediately.

**Chemical analysis:** Samples for mineral analyses were treated as follows. Freeze-dried samples of feces (about 150 mg) were ashed for 17 h at 500°C and extracted with 5 mL of 6 M HCl and brought to 50 mL with demineralised water. For complete recovery of phosphorus, the analysis of this mineral performed at least 5 days after dissolving the ashed material in HCl. Feed samples of about 750 mg were ashed and treated for mineral analysis as feces. The kidney was homogenized using an Ultra Turrax Type Tp 18/10 (Wilten Woltil BV, De Bilt, The Netherlands), in about 3 mL of demineralized water, dried at 105°C, put in an ecsicator for 18 h and weighed again. The dried kidneys were completely ashed for 17 h at 500°C and processed as feces. Urine samples were acidified to pH = 1 with 6 M HCl, centrifuged for 10 min (3000 x g) and the supernatants were frozen at -20°C until analysis.

Calcium and magnesium in diet, feces, urine and kidney samples were analysed in the presence of 1% lanthanum-chloride by atomic absorption spectroscopy using a Varian AA-475 (Varian Techtron, Mulgrave, Australia). Calcium was measured at a wave length of 422.7 nm and air-acethylene ratio of 64:12. Magnesium was measured at a wavelength of 285.3 nm and an air-acethylene ratio of 53:10. Total phosphorus was analysed with a commercial test combination

(ROCHE Phosphate) with the use of a CoBas-Bio auto-analyser (Hoffman-La Roche BV, Mijdrecht, The Netherlands).

Dry matter and nitrogen analyses were performed as described (Yuangklang *et al*., 2005). Sugar concentrations in urine samples pooled per dietary group were determined as silyl derivatives of monosaccharides by gas liquid chromatography as described previously by Schutte *et al*. (1991).

**Statistical analysis:** One-way analysis of variance followed by the Tukey test was used to evaluate differences between the diet groups. The probability of a type I error < 0.05 was taken as the criterion of significance. All analyses were done using SPSS/PC software package (SPSS Inc, Chicago, USA).

## RESULTS

The rats were fed a restricted amount feed and the amount offered was generally consumed. Final body weights and weight gain did not differ between the dietary groups (Table 2). Water intake was significantly increased in the rats fed the galactose diet when compared with those fed the arabinose diet. For other group comparisons there was no difference in water intake. Relative liver weight was not influenced by the type of monosaccharide in the diet. When compared with glucose, the sugars xylose and galacturonic acid had induced an increase in cecum weight, but the increase was even higher with arabinose in the diet. Galactose versus glucose did not affect cecum weight (Table 2). Carcass dry weight was not differentially influenced by the experimental diets (Table 3). For all five diets the carcass contents nitrogen, fat and dry matter were similar.

When compared with glucose, the monosaccharides xylose and galacturonic acid had significantly reduced the urinary pH (Table 4). The urinary pH as induced by either arabinose and galactose were similar. The rats fed the diet containing galactose had produced significantly more

Table 2: Growth performance, water intake, relative liver and cecum weight and carcass composition of the rats fed the experimental diets

| | Diet code | | | | |
|---|---|---|---|---|---|
| Parameters | Glucose | Xylose | Arabinose | Galacturonic acid | Galactose |
| **Body weight (g)** | | | | | |
| Intial, day 0 | 86.20±9.8 | 86.10±9.7 | 86.1±10.4 | 86.0±9.2 | 86.30±11.2 |
| Final, day, 28 | 129.30±5.6 | 126.10±6.8 | 131.6±8.5 | 128.1±10.3 | 130.90±8.5 |
| Weight gain (g day$^{-1}$) | 1.54±0.27 | 1.41±0.18 | 1.60±0.19 | 1.49±0.30 | 1.56±0.25 |
| Relative liver weight (%) | 4.10±0.4 | 4.20±0.5 | 4.1±0.4 | 4.3±0.5 | 4.20±0.5 |
| Relative cecal weight (%) | 0.90±0.2$^{a}$ | 1.60±0.2$^{b}$ | 3.0±0.7$^{c}$ | 2.0±0.4$^{b}$ | 1.00±0.2$^{a}$ |
| **Intake** | | | | | |
| Feed (g day$^{-1}$) | 8.8 | 8.8 | 8.8 | 8.7 | 8.8 |
| Water (mL day$^{-1}$) | 14.2±2.4$^{a,b}$ | 14.1±2.3$^{a,b}$ | 12.8±1.6$^{a}$ | 13.3±1.8$^{a,b}$ | 15.60±2.8$^{b}$ |
| **Carcass analysis** | | | | | |
| Dry weight (g) | 46.2±4.2 | 44.9±4.1 | 45.8±5.4 | 43.7±4.1 | 47.20±5.7 |
| Nitrogen (% of body weight) | 3.4±0.1 | 3.3±0.1 | 3.3±0.1 | 3.3±0.1 | 3.40±0.1 |
| Fat (% of body weight) | 6.4±1.3 | 6.7±1.2 | 5.8±0.4 | 6.4±0.4 | 6.50±1.1 |
| Dry matter (% of body weight) | 31.9±0.9 | 31.9±0.3 | 31.3±0.6 | 31.1±0.2 | 31.80±0.5 |

Values are means±SD for 20 rats per dietary group. The data for carcass analysis are based on 3 pooled samples per dietary group. Values within the same row with different superscript are significantly different ($p<0.05$)

Table 3: Urinary pH, urine and feces production and urinary excretion of sugars in rats fed the experimental diets

| | Diet code | | | | |
|---|---|---|---|---|---|
| Factors | Glucose | Xylose | Arabinose | Galacturonic acid | Galactose |
| **Urine** | | | | | |
| pH | 8.3±0.6$^{b}$ | 7.5±0.8$^{a}$ | 7.6±1.0$^{a,b}$ | 7.0±1.0$^{a}$ | 7.6±1.1$^{a,b}$ |
| Production (mL day$^{-1}$) | 8.8±3.6$^{a,b}$ | 9.8±2.5$^{a,b}$ | 7.5±2.1$^{a}$ | 7.8±3.1$^{a}$ | 10.9±4.1$^{b}$ |
| **Faeces** | | | | | |
| Wet weight (g day$^{-1}$) | 0.7±0.1$^{a}$ | 0.8±0.1$^{b}$ | 1.0±0.1$^{c}$ | 1.0±0.1$^{c}$ | 0.8±0.1$^{a}$ |
| Dry weight (g day$^{-1}$) | 0.5±0.1$^{a}$ | 0.5±0.1$^{b}$ | 0.6±0.1$^{c}$ | 0.6±0.1$^{c}$ | 0.5±0.1$^{a}$ |
| **Urinary excretion** | | | | | |
| Xylose (% of intake) | 0.3 | 34.1 | n.d. | n.d. | n.d. |
| Arabinose (% of intake) | n.d. | n.d. | 13.1 | n.d. | n.d. |
| Galactose (% of intake) | n.d. | n.d. | n.d. | n.d. | 40.3 |
| Uronic acids (% of intake) | 0.2 | 0.2 | 0.2 | 0.1 | 0.3 |

Values are means±SD for 20 rats per dietary group. The data for urinary excretion of sugars are based on pooled samples per dietary group; n.d: Not detectable. Values within the same row with different superscript are significantly different ($p<0.05$)

Table 4: Nitrogen balance and apparent nitrogen absorption in rats fed the experimental diets

| | Diet code | | | | |
|---|---|---|---|---|---|
| Results | Glucose | Xylose | Arabinose | Galacturonic acid | Galactose |
| **Nitrogen** | | | | | |
| Intake (mg day$^{-1}$) | 227.00 | 227.00 | 227.00 | 227.00 | 227.00 |
| Urine (mg day$^{-1}$) | 131.0±14$^{a,b}$ | 134.0±6$^{b}$ | 125.0±9$^{a,b}$ | 120.0±9$^{a}$ | 134.0±24$^{b}$ |
| Feces (mg day$^{-1}$) | 12.3±1.8$^{a}$ | 15.0±1.5$^{b}$ | 19.9±3.4$^{c}$ | 19.5±2.7$^{c}$ | 13.3±1.6$^{a,b}$ |
| Retention (mg day$^{-1}$) | 83.9±15.1 | 78.2±6.2 | 81.7±8.4 | 87.6±10.2 | 79.8±24.5 |
| Apparent absorption (% of intake) | 94.6±0.8$^{c}$ | 93.4±0.7$^{b}$ | 91.2±1.5$^{a}$ | 91.4±1.2$^{a}$ | 94.1±0.7$^{b,c}$ |

Values are means±SD for 20 rats per dietary group. Values within the same row with different superscript are significantly different ($p<0.05$)

urine than those fed the diets with either galacturonic acid or arabinose. Urinary excretion of the ingested sugars was considerable for the rats fed either xylose, arabinose or galactose. In the rats fed the diets containing either glucose or galacturonic acid, sugar excretion was negligible. Feces weight wet and dry weight were increased by the feeding of either xylose, arabinose or galacturonic acid, but not by galactose, when compared with glucose.

The data for the nitrogen balance are shown in Table 5. Urinary nitrogen excretion was lower for the rats fed galacturonic acid when compared with those fed either xylose or arabinose. When compared to glucose, dietary xylose, arabinose and galacturonic acid had increased fecal nitrogen excretion. As a result, apparent nitrogen digestibility was significantly diminished by xylose, arabinose and galacturonic acid when compared with glucose. For the rats fed the diets containing either glucose or galactose, apparent nitrogen digestibility was similar. Group mean values for nitrogen retention were lowest in the rats fed xylose and highest in the rats fed galacturonic acid, but there were no significant differences among the experimental groups.

Urinary calcium excretion was highest in the rats fed the arabinose diet (Table 6). However, when compared with glucose, dietary xylose, galacturonic acid and galactose also raised urinary calcium excretion. Xylose versus glucose and versus the other monosaccharides had significantly lowered fecal calcium excretion, which resulted in a markedly increased apparent absorption of calcium. Calcium retention was significantly raised by feeding the diet containing xylose.

Table 5: Mineral balances and apparent mineral absorption in rats fed the experimental diets

| | Diet code | | | | |
|---|---|---|---|---|---|
| Minerals | Glucose | Xylose | Arabinose | Galacturonic acid | Galactose |
| **Calcium** | | | | | |
| Intake (mg day$^{-1}$) | 43.0 | 42.0 | 43.0 | 42.0 | 42.0 |
| Urine (mg day$^{-1}$) | 0.2±0.1$^{a}$ | 0.6±0.2$^{b}$ | 1.3±0.5$^{c}$ | 0.6±0.2$^{b}$ | 0.5±0.2$^{b}$ |
| Feces (mg day$^{-1}$) | 18.9±4.0$^{b}$ | 11.2±3.9$^{a}$ | 17.8±3.3$^{b}$ | 19.8±9.5$^{b}$ | 17.7±1.6$^{b}$ |
| Retention (mg day$^{-1}$) | 23.9±4.0$^{b}$ | 30.3±3.8$^{a}$ | 24.0±3.2$^{b}$ | 21.6±9.4$^{b}$ | 23.8±1.6$^{b}$ |
| Apparent absorption (% of intake) | 56.1±9.2$^{a}$ | 73.4±9.2$^{b}$ | 58.6±7.7$^{a}$ | 52.8±22.5$^{a}$ | 57.8±3.9$^{a}$ |
| **Magnesium** | | | | | |
| Intake (mg day$^{-1}$) | 3.7 | 3.9 | 3.7 | 3.6 | 3.8 |
| Urine (mg day$^{-1}$) | 0.6±0.1$^{a}$ | 1.0±0.3$^{b}$ | 1.5±0.5$^{c}$ | 1.6±0.4$^{c}$ | 0.9±0.3$^{a,b}$ |
| Feces (mg day$^{-1}$) | 1.9±0.4$^{d}$ | 1.0±0.2$^{a}$ | 0.6±0.3$^{b}$ | 0.7±0.2$^{b}$ | 1.3±0.2$^{c}$ |
| Retention (mg day$^{-1}$) | 1.2±0.4$^{a}$ | 1.9±0.4$^{c}$ | 1.7±0.5$^{b,c}$ | 1.4±0.3$^{a,b}$ | 1.6±0.3$^{b,c}$ |
| Apparent absorption (% of intake) | 48.6±10.0$^{a}$ | 73.8±5.2$^{c}$ | 84.2±7.0$^{d}$ | 81.9±4.4d | 65.3±6.2$^{b}$ |
| **Phosphorns** | | | | | |
| Intake (mg day$^{-1}$) | 39.0 | 37.0 | 36.0 | 39.0 | 35.0 |
| Urine (mg day$^{-1}$) | 14.0±1.5$^{a}$ | 15.5±1.2$^{a}$ | 13.4±2.1$^{a}$ | 19.6±1.7$^{b}$ | 14.5±6.0$^{a}$ |
| Feces (mg day$^{-1}$) | 12.7±2.0$^{c}$ | 11.1±1.1$^{b}$ | 12.7±2.1$^{c}$ | 4.5±1.1$^{a}$ | 11.7±1.1$^{b,c}$ |
| Retention (mg day$^{-1}$) | 12.3±2.7$^{b,c}$ | 10.4±1.8$^{a,b}$ | 9.8±3.2$^{a,b}$ | 14.9±1.9$^{c}$ | 8.8±5.8$^{a}$ |
| Apparent absorption (% of intake) | 67.4±5.2$^{a,b}$ | 69.9±3.0$^{b}$ | 64.6±5.7$^{a}$ | 88.4±2.9$^{c}$ | 66.6±3.3$^{a,b}$ |

Values are means±SD for 20 rats per dietary group. Values within the same row with different superscript are significantly different ($p<0.05$)

Table 6: Kidney weight and mineral composition in rats fed the experimental diets

| | Diet code | | | | |
|---|---|---|---|---|---|
| Kidney measures | Glucose | Xylose | Arabinose | Galacturonic acid | Galactose |
| Relative weight (%) (g/100 g body weight) | 0.50±0.0 | 0.50±0.0 | 0.500±0.1 | 0.500±0.0 | 0.5±0.0 |
| Dry weight (mg) | 128.00±9.0$^{b}$ | 122.00±9.0$^{a,b}$ | 124.00±12.0$^{a,b}$ | 116.00±9.0$^{a}$ | 127.00±14$^{b}$ |
| Calcium (% of dry weight) | 0.60±0.5$^{a}$ | 0.50±0.4$^{a}$ | 0.90±1.0$^{a,b}$ | 1.20±0.8$^{b}$ | 0.50±0.4$^{a}$ |
| Magnesium (% of dry weight) | 0.09±0.02$^{a,b}$ | 0.09±0.01$^{b}$ | 0.10±0.02$^{b}$ | 0.10±0.03$^{b}$ | 0.07±0.02$^{a}$ |
| Phoshorus (% of dry weight) | 1.50±0.2 | 1.50±0.3 | 1.60±0.5 | 1.80±0.5 | 1.50±0.2 |

Values are means±SD for 20 rats per dietary group. Values within the same row with different superscript are significantly different ($p<0.025$)

The excretion of magnesium with urine was highest for the rats fed the diets containing arabinose or galacturonic acid (Table 6). However, xylose versus glucose also raised urinary magnesium excretion. All four monosaccharides lowered fecal magnesium excretion when compared with glucose, the most pronounced lowering effect being caused by arabinose and galacturonic acid. Apparent magnesium absorption was highest in the rats fed the diets containing either arabinose or galacturonic acid, but xylose and galactose also raised magnesium absorption significantly when compared with glucose.

Phosphorus excretion with urine was significantly elevated in the rats fed the diet with galacturonic acid when compared with the other dietary groups (Table 6). Compared with glucose, xylose had slightly lowered fecal phosphorus excretion whereas galacturonic acid had produced a

marked decrease. Galacturonic acid versus the other monosaccharides induced a pronounced increase in apparent phosphorus absorption.

Kidney dry weight was lower in the rats fed galacturonic acid than in those fed either the glucose or galactose diet (Table 6). When expressed relative to body weight, kidney weight was similar for the five dietary groups. The diet containing galacturonic acid had caused significantly higher kidney calcium concentrations than the diets containing either glucose, xylose or galactose. The galactose diet induced lower kidney magnesium concentrations than did the diets with either xylose, arabinose or galacturonic acid. Kidney phosphorus levels did not differ between the dietary groups.

## DISCUSSION

In broiler chickens with free access to feed, the administration of diets containing either xylose or arabinose instead of glucose showed impaired growth performance (Schutte, 1990). The rats in this study were fed restrictedly, but were given identical weights of the experimental diets. There was no diet effect on body-weight gain. This outcome is surprising, especially for the xylose, arabinose and galactose groups, because substantial amounts of the dietary sugars were recovered in urine. Recovery of the ingested sugars in urine would imply that for the animals there was less metabolic energy available for growth. The carcass composition of the animals fed the diets containing either xylose, arabinose or galactose was similar to that of the other groups. It can therefore be excluded that the rats fed xylose, arabinose or galactose had deposited more nitrogen and thus had more lean-body mass and more body water. The data would indicate that the five monosaccharides induced similar body-weight gain with similar composition. It remains unknown how the loss of metabolic energy by the xylose, arabinose and galactose groups was compensated for in order to allow unchanged growth.

Apparent nitrogen absorption was reduced by the feeding of either xylose, arabinose or galacturonic acid when compared to glucose. Dietary galactose did not affect apparent nitrogen absorption. Relative cecum weight was increased by xylose, arabinose or galacturonic acid, but by not galactose. Relative cecum weight, including its contents, may be considered as an index of bacterial fermentation. The non-absorbed sugars will reach the cecum and stimulate bacterial growth in the cecal lumen, leading to the production of short chain fatty acids and retention of water through osmosis. Thus, an increased cecum weight points at enhanced bacterial growth and incorporation of nitrogen into bacterial protein. In the cecum and colon there is no protein absorption so that increased bacterial protein synthesis causes additional fecal nitrogen excretion. This in turn leads to lowering of apparent nitrogen absorption (Nyman and Asp, 1982). The extra fecal excretion of bacterial mass in the rats fed xylose, arabinose or galacturonic acid is reflected by the observed increase in fecal wet and dry weight. The decrease in apparent nitrogen absorption seen in the rats fed either xylose, arabinose or galacturonic acid can be explained by enhanced bacterial fermentation. It is possible that true ileal protein digestion was not affected.

In rats, the feeding of the non-digestible disaccharide lactose or native resistant starch has been shown to stimulate the apparent absorption of magnesium, calcium and phosphorus (Heijnen *et al*., 1993; Schulz *et al*., 1993). This effect was explained by bacterial fermentation of lactose in the intestinal lumen, causing a lowering of the pH of the intestinal contents (Heijnen *et al*., 1993). The lowering of pH will raise the solubility of magnesium, calcium and phosphate in the intestinal contents (Heijnen *et al*., 1993), which increases their availability for absorption (Brink *et al*., 1992). The impact of pH lowering is greatest on magnesium solubility and smallest on phosphate solubility

(Heinen *et al*., 1993). In this study, the absorption of magnesium was stimulated by the feeding of xylose, arabinose, galacturonic acid and galactose. Possibly, these effects relate to a lowering of the pH in the ileal contents. Dietary galactose raised relative cecum weight numerically, but not statistically, pointing at less bacterial fermentation than after feeding the other three sugars. This could explain why dietary galactose had induced the smallest increase in apparent magnesium absorption. However, it is difficult to see why apparent calcium absorption was enhanced by xylose only and phosphorus absorption was raised by galacturonic acid only.

The diet containing galacturonic acid produced a significant increase in kidney concentrations of calcium when compared with the glucose diet. A similar effect of galacturonic acid was seen in an earlier study with female rats, but it failed to reached statistical significance (Mohamed *et al*., 2010). Due to the addition of sodium carbonate to the diet, the values for urinary pH in our earlier study were higher than those in this study. Acidification of urine by either feeding a high-protein diet (Van Camp *et al*., 1990) or a diet with ammonium chloride (Kootstra *et al*., 1991) is associated with inhibition of nephrocalcinogenesis. Possibly, the high urinary pH values in our earlier study had masked the effect of galacturonic acid on nephrocalcinogenesis.

The major determinants of nephrocalcinogenesis are low magnesium intakes (Bunce *et al*., 1965), high phosphorus intakes and high calcium intakes (Mars *et al*., 1988; Hoek *et al*., 1988). Thus, it could be suggested that galacturonic acid versus glucose had inhibited the absorption of magnesium and/or stimulated the absorption of phosphorus and/or calcium. The concentrations in urine of magnesium, calcium and phosphorus may be indicative of those in the tubular fluid and thus relate to the intratubular formation of calcium phosphate precipitates, that is nerphrocalcinosis. High concentrations of calcium and phosphorus will stimulate nephrocalcinogenesis, whereas high magnesium concentrations can be expected to inhibit this process (Greenwald, 1945; Boulet *et al*., 1962). Dietary galacturonic acid versus glucose significantly raised the urinary excretion of calcium, magnesium and phosphorus. It can be suggested that the stimulatory effect of urinary calcium and phosphorus on nephrocalcinogenesis had overridden the inhibitory effect of urinary magnesium.

In conclusion, this study with rats shows that the feeding of xylose, arabinose, galacturonic acid or galactose did not influence body-weight gain and carcass composition. However, the monosaccharides did influence apparent nitrogen absorption and mineral metabolism. There were differences between the effects of sugar type in terms of statistical significance and magnitude.

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