# Dietary purified β-glucan reduces peak glucose absorption and portal insulin release in portal-vein catheterized grower pigs ☆

S. Hooda [a], J.J. Matte [b], T. Vasanthan [a], R.T. Zijlstra [a],*

[a] *University of Alberta, Edmonton, Alberta, Canada*
[b] *Agriculture and Agri-Food Canada, Sherbrooke, Quebec, Canada*

## ARTICLE INFO

## ABSTRACT

Kinetics of glucose absorption may affect insulin secretion into the portal vein. The role of wet-fractionated oat β-glucan on these variables is unknown; thus, three 35-kg pigs were fitted with catheters in the portal vein and carotid artery and a portal vein flow probe. Pigs were fed 3 diets containing 0, 3, or 6% purified β-glucan for 7-d in a repeated $3 \times 3$ Latin square. On d 7, blood was sampled for 12 h postprandially. Net glucose absorption rate was calculated from plasma portal-arterial differences × flow. Blood flow increased ($P<0.001$) after feeding, without a diet effect. Postprandially, β-glucan reduced ($P<0.05$) net glucose absorption during the first h by 22 to 51%. At 30 and 90 min postprandially, β-glucan decreased ($P<0.05$) portal release of C-peptide but did not affect portal insulin at 30 min, indicating that β-glucan reduces peak insulin release while maintaining prehepatic insulin homeostasis. In conclusion, oat β-glucan as a soluble, viscous fibre decreases rate of glucose absorption and peak insulin release in portal vein.

## 1. Introduction

Dietary nutrient characteristics affect kinetics of nutrient absorption, incretin and pancreatic hormone responses, and nutrient metabolism. Among nutrients, non-starch polysaccharides (NSP) may decrease peak glucose absorption, because soluble NSP increase digesta viscosity (Bach Knudsen et al., 2005). The kinetics of glucose absorption affects glucose metabolism and insulin response (Jenkins et al., 1995). Reduced postprandial glucose and insulin responses have significance in control and prevention of type-II diabetes. Among soluble NSP, purified β-glucans from oat and barley have been studied in humans in relation to glucose metabolism using glucose measurements in peripheral blood (Panahi et al., 2007). However, glucose homeostasis is tightly controlled by insulin and glucagon in the systemic circulation in normal human

subjects. Thus, a porcine catheterization model was used to test the hypothesis that β-glucan as a soluble NSP decreases peak glucose absorption and insulin response. Insulin responses are measured using plasma insulin; however, considering hepatic insulin extraction, C-peptide released from proinsulin is a more reliable indicator of insulin release (Polonsky and Rubenstein, 1984). Thus, the objective was to measure effects of oat β-glucan on glucose absorption and portal insulin release in portal-arterial catheterized grower pigs.

## 2. Materials and methods

### 2.1. Surgery, diets and feeding

The animal protocol was approved by the Animal Care and Use Committee for Livestock at the University of Alberta and was conducted at the Swine Research and Technology Centre. Three female pigs (35 to 40 kg BW) were catheterized in the portal vein and carotid artery using modified polyvinyl tube catheters; 14-mm blood flow probes

(Transonic Systems, Ithaca, NY) were implanted around the portal vein (Hooda et al., 2009a).

Ten d post surgery, pigs were fed one of the three diets based on wheat and soybean meal supplemented with 0, 3, and 6% (BG0, BG3, and BG6; Table 1) of purified β-glucan oat (Viscofiber; Cevena Bioproducts, Edmonton, AB, Canada). Pigs were fed diets for 1 week in a double $3 \times 3$ Latin square blocked by time, to have 6 observations per diet. Pigs were fed 1000, 1100, 1200, and 1500 g/d till 40, 45, 50, and 65 kg BW, respectively. Feed was divided into two equal meals and fed at 0800 and 2000 with free access to water.

### 2.2. Sampling and analysis

Blood samples were collected from pigs 1 d every wk for 6 wk in heparinized tubes from the carotid artery and portal vein. Blood was collected every 15 min from −15 to 60 min, then every 30 min to 240 min, then every 60 min to 480 min, and 600 min and 720 min postprandially; blood flow was measured simultaneously. During measurements, the probe was attached to the flowmeter with a cable. Flow was recorded continuously at each collection for 10 min using windaq software. Plasma was analyzed for glucose (Glucose oxidase kit; Diagnostics Chemicals Ltd., Charlottetown, PEI, Canada), insulin (Porcine Insulin RIA kit; Linco, St. Louis, MO) and C-peptide (Porcine C-peptide RIA kit; Linco, St. Louis, MO). Plasma flow rate was calculated from blood flow using the equation; plasma flow = blood flow × (1 − (hematocrit/100)).

### 2.3. Calculations and statistical analysis

Net glucose absorption was calculated from the plasma portal-arterial differences and plasma flow measurements using the formula $q = (Cp - Ca)F(dt)$ (Rerat et al., 1980). Cumulative net glucose absorption was calculated subsequently using the formula $Q = \sum_{t0}^{t1} q$.

In the formulas, $q$ is the amount of nutrients absorbed within time period d$t$, $Cp$ and $Ca$ are concentrations of nutrients in the portal vein and carotid artery, respectively, $F$ is plasma flow in the portal vein, and $Q$ is the amount of nutrient absorbed from time $t_0$ to $t_1$. The term net glucose absorption is used for net portal appearance of glucose after utilization of glucose by intestine. Carotid and portal glucose and hormones and net glucose absorption were analyzed as repeated measures using the MIXED procedure of SAS (version 9.1; SAS Inst. Inc., Cary, NC) with level of significance at $P<0.05$. The statistical model included fixed effects of diet and time and their interaction and random effects of pig and collection period.

**Table 1**
Ingredient composition of diets [a].

| Ingredient (%) | BG0 | BG3 | BG6 |
|---|---|---|---|
| Wheat | 72.20 | 66.48 | 60.77 |
| Soybean meal | 22.00 | 20.35 | 18.70 |
| Canola oil | 1.80 | 1.67 | 1.55 |
| Vitamin and mineral premix | 4.00 | 4.00 | 4.00 |
| Oat BG [b] | 0.00 | 7.50 | 15.00 |

[a] BG = β-glucan; 0, 3, and 6%.
[b] 50% oat β-glucan (Viscofiber; Cevena Bioproducts, Edmonton, AB, Canada).
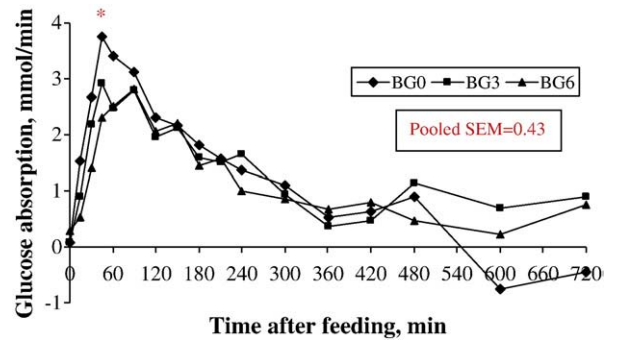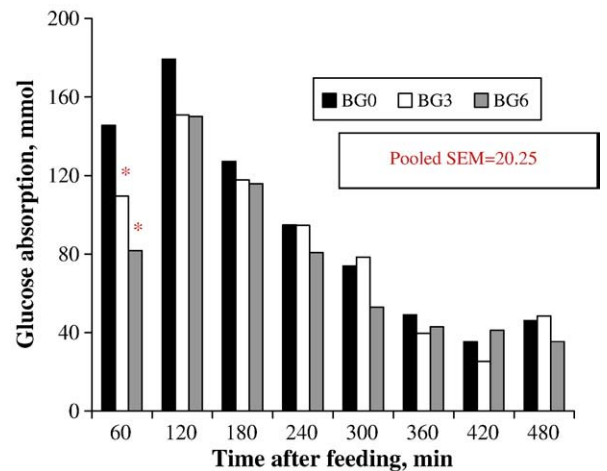


**Fig. 1.** Rate of absorption of glucose (mmol/min) after feeding 3 diets. BG0, control diet; BG3, 3% β-glucan diet; and BG6, 6% β-glucan diet (based on 6 observations). The pooled SEM is 0.43 and $P<0.05$ at 45 min after feeding. * Different from control diet ($P<0.05$).

### 3. Results

Diet analyses indicated a similar gross energy content for the three diets; however, starch content was proportionally higher in BG0 than BG3 and BG6 (39.1, 36.1, and 33.4%, respectively). Total NSP content was higher for β-glucan diets than control (9.1, 15.8, and 18.4%) with β-glucan content slightly higher than expected (BG0, 0.55%; BG3, 3.80%; and BG6, 6.26%).

Portal blood flow was 0.86 L/min before feeding and increased ($P<0.001$) to 1.33 L/min maximum and then decreased to prefeeding level at 120 min postprandial and was not influenced by diet (data not shown). Rate of glucose absorption increased ($P<0.05$) immediately after feeding, peaked 45 min ($P<0.05$) postprandially, and was decreased ($P<0.05$) by 6% β-glucan (Fig. 1). The decrease in glucose absorption rate by β-glucan lowered ($P<0.05$) total glucose absorption during first h postprandially by 22 to 51% after feeding BG3 and BG6 diets, respectively (Fig. 2). At 30 min postprandial, portal insulin peaked for all diets and did not differ among diets. At 90 min postprandial, portal insulin was lower ($P<0.05$) after feeding the BG6 diet (Fig. 3). In the portal vein, C-peptide release was highest ($P<0.05$) with the BG0 diet from 30 to 90 min postprandial and



**Fig. 2.** Total glucose absorption (mmol) after feeding 3 diets. BG0, control diet; BG3, 3% β-glucan diet; and BG6, 6% β-glucan diet (based on 6 observations). The pooled SEM is 20.25 and $P<0.05$ at 60 min after feeding. * Different from control diet ($P<0.05$).
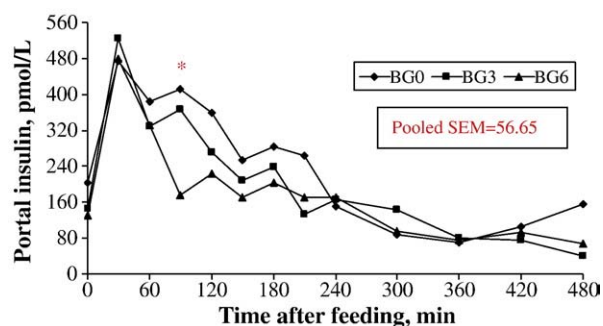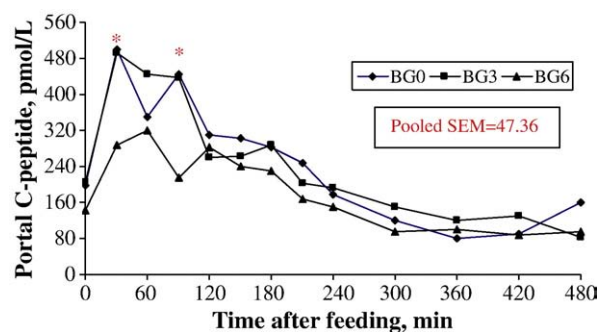
**Fig. 3.** Portal plasma insulin (pmol/L) after feeding 3 diets. BG0, control diet; BG3, 3% β-glucan diet; and BG6, 6% β-glucan diet (based on 6 observations). The pooled SEM is 56.65 and P<0.05 at 90 min after feeding. * Different from control diet (P<0.05).

then decreased to prefeeding at 240 min postprandially (Fig. 4). The BG6 but not BG3 diet decreased (P<0.05) insulin release at 30 and 90 min after feeding.

## 4. Discussion

Portal-arterial catheterization demonstrated the effects of purified oat β-glucan on quantitative absorption of glucose and insulin release. Peak glucose absorption and total absorption during first hour after feeding were reduced by 6% β-glucan, similar to other studies with soluble NSP (Serena et al., 2008; Ellis et al., 1995). The decreased glucose absorption was due to oat β-glucan causing a high solubility, and increasing water-binding capacity and viscosity of gastrointestinal contents (Hooda et al., 2009b); however, the role of gastric emptying cannot be ignored.

In the pancreas, equimolar amounts of C-peptide are released from proinsulin during insulin secretion. However, unlike insulin, prehepatic and hepatic extraction of C-peptide is negligible and C-peptide is thus a reliable indicator of insulin secretion (Guan et al., 2000). The early differences detected for C-peptide (30 and 90 min postfeeding) as compared to insulin (90 min postfeeding) emphasized the importance of measuring C-peptide along with insulin. Decreased peak portal C-peptide but not insulin at 30 min postfeeding reflects better conservation (less metabolized or utilized) of insulin between pancreas and liver



**Fig. 4.** Portal plasma C-peptide (pmol/L) after feeding 3 diets. BG0, control diet; BG3, 3% β-glucan diet; and BG6, 6% β-glucan diet (based on 6 observations). The pooled SEM is 47.36 and P<0.05 at 30 and 90 min after feeding. * Different from control diet (P<0.05).

in 6% β-glucan. The attenuated pancreatic insulin response brought by 6% β-glucan on portal C-peptide was probably due to reduced glucose absorption, because glucose absorption directly regulates pancreatic insulin release (Ellis et al., 1995). Lacking glucose and insulin responses with 3% β-glucan indicate that higher amounts are needed to achieve desired digesta viscosity and nutrient absorption kinetics.

The present study demonstrated effects of 6% of oat β-glucan in lowering peak glucose absorption concurrently with an attenuated insulin response that further add to the body of knowledge concerning purified, dietary NSP. The lowered quantitative glucose absorption and insulin release from pancreas by purified NSP has implications in the management of human metabolic disease. Possible underlying physiological mechanisms of effects of purified β-glucan through solubility and viscosity were demonstrated in another study (Hooda et al., 2009b). The role of gastric emptying cannot be ignored and requires further study.

## Conflict of interest

None of the authors has a conflict of interest.

## Acknowledgments

## References

Bach Knudsen, K.E., Serena, A., Kjaer, A.B.K., Jorgensen, H., Engberg, R., 2005. Rye bread enhances the production and plasma concentration of butyrate but not the plasma concentrations of glucose and insulin in pigs. J. Nutr. 135, 1696–1704.

Ellis, P.R., Roberts, F.G., Low, A.G., Morgan, L.M., 1995. The effect of high molecular-weight guar gum on net apparent glucose absorption and net apparent insulin and gastric inhibitory polypeptide production in growing pig: relationship to rheological changes in jejunal digesta. Br. J. Nutr. 74, 539–556.

Guan, X., Matte, J.J., Ku, P.K., Snow, J.L., Burton, J.L., Trottier, N.L., 2000. High chromium yeast supplementation improves glucose tolerance in pigs by decreasing hepatic extraction of insulin. J. Nutr. 130, 1274–1279.

Hooda, S., Matte, J.J., Wilkinson, C.W., Zijlstra, R.T., 2009a. Technical Note: an improved surgical model for the long-term studies of kinetics and quantification of nutrient absorption in swine. J. Anim. Sci. 87, 2013–2019.

Hooda S, Metzler-Zebeli BU, Vasanthan T, Zijlstra RT. 2009b. Effects of viscosity and fermentability of purified non-starch polysaccharides (NSP) on ileal and total tract nutrients digestibility in ileal-cannulated grower pigs. Livest. Sci. (Submitted).

Jenkins, D.J.A., Josse, R.G., Jenkins, A.L., Wolever, T.M.S., Vuksan, V., 1995. Implications of altering the rate of carbohydrate absorption from the gastrointestinal tract. Clin. Invest. Med. 18, 296–302.

Panahi, S., Ezatagha, A., Temelli, F., Vasanthan, T., Vuksan, V., 2007. Beta-glucan from two sources of oat concentrates affect postprandial glycemia in relation to the level of viscosity. J. Am. Coll. Nutr. 26, 639–644.

Polonsky, K.S., Rubenstein, A.H., 1984. C peptide as a measure of the secretion and hepatic extraction of insulin; pitfalls and limitations. Diabetes 33, 486–494.

Rerat, A., Vaugelade, P., Villiers, P., 1980. A new method for measuring the absorption of nutrients in the pig: Critical examination. Current Concepts of Digestion and Absorption in Pigs. In: Low, A.G., Partridge, I.G. (Eds.), National Institute for Research in Dairying. Reading, England, Hannah Research Institute, Ayr, Scotland, pp. 177–216. Tech. Bull. 3.

Serena, A., Jorgensen, H., Bach Knudsen, K.E., 2008. Absorption of carbohydrate derived nutrients in sows as influenced by types and contents of dietary fiber. J. Anim. Sci. 87, 136–147.