Effects of whole grain on metabolic risk factors; evidences from acute- and second meal studies

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Health benefits of WG diets

Epidemiological evidence
- WG intake inversely related to risk of obesity, typ2 diabetes and CVD

Suggested mechanisms for protective effects
- Source of DF
- Source of minerals and trace elements
- Source of methyl-doners
- Source of anti-oxidants/phenolics
- Low GI
- Source of prebiotics (e.g. DF, RS, fructans, phenolics)
Modulation of gut microbiota

- Oligo-fructose
- AXOS

Prebiotics

Less LPS

SCFA

Stimulation of L-cells

e.g. GLP-1, GLP-2, PYY

Appetite regulation

ghrelin

Inflammation
- liver, muscles and adipose tissue

Benefits on metabolism and appetite regulation

Adopted from Cani & Delzenne
Prebiotic effects of indigestible carbohydrates in WG products

Experiences from meal studies in healthy humans
“Over-night” effects of different cereal based evening meals, on metabolic parameters at a subsequent standardised breakfast

15 healthy subjects
22-32y, BMI 22.1 2.0

Evening reference and test meals
(50 g available starch);

• White wheat bread (WWB)
• Low GI Barley Kernel (BK) products rich in RS and DF
• “Simulated BK” products WWB with added RS and/or barley DF

 Metabolic parameters; B-glucose, insulin, inflammatory markers, incretins
Satiety; Subjective rating
Colonic fermentation parameters; H₂ breath tests, p-SCFA

Standardised breakfast:
White wheat bread (WWB)
(50 g available starch)

10h

Over-night effects of certain whole grain products on glycaemia and related risk markers in healthy subjects

- Reduction of blood glucose area at a standardised breakfast
  - Obtained post evening meals with low GI Barley Kernel (BK) products rich in DF & RS
  - Obtained with WWB added with barley DF and RS to simulate content in BK products.

- Positively correlated with markers of colonic fermentation (breath H₂ and p-butyric acid)
- Inversely correlated with markers of insulin resistance (s-FFA) and inflammation (p-IL-6)
- Positively correlated with anti-inflammatory markers (p-adiponectin)
- Positively correlated with p-GLP1; an antidiabetic and satiating hormone

Blood glucose

Evening meals; White reference bread, WG BK, or "simulated BK" test products

Standardised breakfast

Blood glucose response (IAUC) at a standardised breakfast following different evening test meals
(WWB white wheat bread; BK barley kernel bread)

<table>
<thead>
<tr>
<th>Evening test meals</th>
<th>IAUC (0 – 120 min) mmol×min/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>WWB ref</td>
<td>211.6 ± 23.8</td>
</tr>
<tr>
<td>WWB + RS</td>
<td>167.2 ± 21.3</td>
</tr>
<tr>
<td>½ portion BK</td>
<td>160.4 ± 16.4</td>
</tr>
<tr>
<td>High amylose BK</td>
<td>152.1 ± 17.0</td>
</tr>
<tr>
<td>High DF+RS BK</td>
<td>149.9 ± 19.3</td>
</tr>
<tr>
<td>WWB+RS+DF</td>
<td>156.8 ± 17.0</td>
</tr>
<tr>
<td>Ordinary BK</td>
<td>149.9 ± 19.3</td>
</tr>
<tr>
<td>High RS BK</td>
<td>142.2 ± 14.1</td>
</tr>
</tbody>
</table>

*IAUC lower (P<0.05) compared with after WWB evening meal
Fasting serum free fatty acids (FFA) – a marker of insulin resistance – prior to breakfast following different evening bread test meals (WWB white wheat bread; BK barley kernel bread)

<table>
<thead>
<tr>
<th>Test evening meals</th>
<th>Fasting FFA (mmol/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WWB</td>
<td>0.40 ± 0.04</td>
</tr>
<tr>
<td>1/2 portion BK</td>
<td>0.32 ± 0.03</td>
</tr>
<tr>
<td>WWB + RS + DF</td>
<td>0.32 ± 0.03</td>
</tr>
<tr>
<td>WWB + RS</td>
<td>0.27 ± 0.03</td>
</tr>
<tr>
<td>Cut BK</td>
<td>0.24 ± 0.03</td>
</tr>
<tr>
<td>ordinary BK</td>
<td>0.21 ± 0.01</td>
</tr>
</tbody>
</table>

S-FFA was positively related to the glucose AUC 0-120 min and the glucose peak; $r=0.37$, $P<0.001$ and $r=0.28$, $P=0.01$, respectively
Breath hydrogen at a standardised breakfast following different evening bread test meals
(WWB white wheat bread; BK barley kernel bread)

Test evening meals

Breath H$_2$ was inversely related to Glucose AUC 0-120 min; $r$=-0.25, $P<0.05$
Markers of colonic fermentation (Plasma SCFA’s) vs. B-glucose AUC, insulin AUC and fasting serum FFA at the standardised breakfast

<table>
<thead>
<tr>
<th>Plasma SCFA</th>
<th>Glucose AUC 0-120 min</th>
<th>Insulin AUC 0-120 min</th>
<th>Fasting p-FFA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>p</td>
<td>r</td>
</tr>
<tr>
<td>Fasting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butyrate</td>
<td>-0.30</td>
<td>0.006</td>
<td>-0.19</td>
</tr>
<tr>
<td>Propionate</td>
<td>0.08</td>
<td>0.46</td>
<td>-0.12</td>
</tr>
<tr>
<td>Acetate</td>
<td>0.15</td>
<td>0.16</td>
<td>-0.01</td>
</tr>
<tr>
<td>30 min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butyrate</td>
<td>-0.23</td>
<td>0.009</td>
<td>-0.08</td>
</tr>
<tr>
<td>Propionate</td>
<td>0.16</td>
<td>0.13</td>
<td>0.08</td>
</tr>
<tr>
<td>Acetate</td>
<td>0.12</td>
<td>0.28</td>
<td>-0.06</td>
</tr>
</tbody>
</table>
Plasma adiponectin and IL-6 levels at a standardized breakfast, post evening test meals with white wheat bread (WWB) or ordinary barley kernel bread (BK) (healthy subjects)
Plasma GLP-1 (Glucagon-Like Peptide-1) response after a standardised breakfast following different evening test meals

P GLP-1 negatively related to glucose AUC (0-120min)
\[ r = -0.26, P < 0.05 \]
Subjective satiety at a standardised breakfast following different cereal based evening test meals

Evening reference and test meals

- White wheat bread (WWB)
- Low GI Barley Kernel (BK) products rich in DF & RS
- “Simulated “ BK products WWB with added RS and/or barley DF

Subjective rating of satiety (AUC 0–180 min) after standardised breakfast positively related to breath H2 (mean 0–180 min) ; r=0.27, P<0.01

Blood glucose response after different cereal breakfasts. Cumulative responses after a standardized lunch and dinner (healthy subjects)

**Incremental glycaemic area (mM x min)**

- **Breakfast**
- **+ Lunch**
- **+ Lunch + Dinner**

**Dietary fibre + Resistant starch (g/portion)**

<table>
<thead>
<tr>
<th>Breakfast</th>
<th>White bread</th>
<th>Barley porridge</th>
<th>Oat kernels</th>
<th>Wheat kernels</th>
<th>Rye kernels</th>
<th>Barley kernels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakfast</td>
<td>100</td>
<td>112</td>
<td>85</td>
<td>79*</td>
<td>72*</td>
<td>48*</td>
</tr>
<tr>
<td>+ Lunch</td>
<td>3,1</td>
<td>12,7</td>
<td>12,7</td>
<td>14,4</td>
<td>19,8</td>
<td>18,6</td>
</tr>
<tr>
<td>+ Lunch + Dinner</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*P< 0.05

Acute Glycaemic- and Insulinaemic responses to rye and wheat breakfast meals

- ERB – Endosperm Rye Bread
- ERB_Lac – ERB + lactic acid
- WGRB – Whole Grain Rye Bread
- WGRB_Lac – WGRB + lactic acid
- RK – Rye Kernels/boiled
- WK – Wheat Kernels/boiled
- WWB – White Wheat Bread
Subjective rating of fullness in the early post-prandial phase after breakfast (0-45 min)

- WWB – White Wheat Bread
- ERB – Endosperm Rye Bread
- ERB_Lac – ERB + lactic acid
- WGRB – Whole Grain Rye Bread
- WGRB_Lac – WGRB + lactic acid
- RK – Rye Kernels/boiled
- WK – Wheat Kernels/boiled
Post-prandial metabolism and satiety after rye and wheat breakfasts, and voluntary food intake at a subsequent lunch meal

↑ Early satiety (AUC 0-45 min)

↓ GI

↓ Insulin response

↑ Late satiety (210-270 min)

↓ Late total ghrelin (270 min)

↓ Energy intake lunch 270 min

(0 min) Test breakfasts

(270 min) Ad lib lunch

Blood glucose ↓
Insulin response ↓
GI ↑
Early satiety (AUC 0-45 min)
Glycaemic profile (GP) = the duration for the incremental postprandial blood glucose response / incremental blood glucose peak (min/mM)

<table>
<thead>
<tr>
<th></th>
<th>Rye kernels</th>
<th>Wheat kernels</th>
<th>White wheat bread (WWB)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GI</strong></td>
<td>73 ± 8.4 (^b)</td>
<td>68 ± 9.4 (^b)</td>
<td>100 ± 9.4 (^a)</td>
</tr>
<tr>
<td><strong>GP</strong></td>
<td>94.2 ± 12.6 (^a)</td>
<td>50.7 ± 7.0 (^b)</td>
<td>49.1 ± 7.3 (^b)</td>
</tr>
</tbody>
</table>

**Glycaemic profile (GP)**

*Glycaemic profile (GP)* is a measure of the course of glycaemia, reflecting the duration of the incremental postprandial blood glucose response and the incremental blood glucose peak.
Metabolism and satiety after rye and wheat breakfasts, and voluntary food intake at a subsequent lunch meal.

- **↑ Early satiety** (AUC 0-60 min)
- **↓ Insulin response**
- **↑ GI**
- **↑ Glycaemic profile (GP)**
- **↑ Late satiety** (210-270 min)
- **↓ Late total ghrelin (270 min)**
- **↓ Energy intake lunch 270 min**

Test breakfasts (0 min) Ad lib lunch (270 min)
Effects of rye and wheat breakfasts on breath $H_2$ during the course of breakfast and a subsequent ad lib lunch

- Breath $H_2$ detected in the acute postprandial phase, particularly with certain WG rye products
- Breath $H_2$ (AUC 120-270 min) positively correlated with a smoother course of glycaemia (lower peak response of longer duration) (high Glycaemic Profile)
- Breath $H_2$ prior to lunch (270 min) negatively correlated with p-FFA (marker of insulin resistance)
- Breath $H_2$ prior to lunch (120-270min) related to lower energy intake at subsequent ad libitum lunch
Conclusion

- BK products may beneficially affect glycaemic regulation, markers of insulin sensitivity & inflammation, and appetite regulation in healthy subjects through a prebiotic mechanism involving colonic fermentation, and GLP-1 production.

- A BK evening meal improves metabolic variables, reduces caloric intake, and reduces rating of hunger over breakfast & lunch the subsequent day.

- Evidence from acute and over-night studies with BK - and rye products, might indicate rapid prebiotic processes. The prebiotic effect of BK products in an over-night perspective appears to be linked to the presence of barley DF and RS.

- A prebiotic mechanism might contribute to health benefits seen with WG diets in observational studies. Longer term WG intervention studies are needed, and should preferably consider the prebiotic potential (and GI/GP features) of included WG foods, as well as possible synergies with prebiotics present in the “background” diet.
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