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Evidence for effects of oat [beta]-glucan on satiety and weight control

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Evidence for effects of oat β -glucan on satiety and weight control

A thesis submitted in fulfilment of the requirements for the award of the degree

Doctor of Philosophy

from

University of Wollongong

by

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DECLARATION

I hereby declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Health Sciences, University of Wollongong, is my own work unless otherwise referenced or acknowledged. This document has not been submitted in whole, or in part, for qualifications at any other academic institution.

Eleanor J. Beck

Date:

DEDICATION

To

Mum, Dad and Craig

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LIST OF ABBREVIATIONS

AACC	American Association of Cereal Chemists
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
AUC	Area Under the Curve
β -glucan	(1 \rightarrow 3)(1 \rightarrow 4) Beta-D-glucan
BMI	Body Mass Index
CCK	Cholecystokinin
DPPIV	Dipeptidyl peptidase IV
EDTA	Ethylenediaminetetraacetic acid
ES1	Excellent Source of fibre under current regulation
ES2	Excellent Source of fibre under proposed regulation
FDA	Food and Drug Administration
FSANZ	Food Standards Australia New Zealand
GI	Glycaemic Index
GIT	Gastrointestinal Tract
GLP-1	Glucagon-like-peptide-1
GS1	Good Source of fibre under current regulation
GS2	Good Source of fibre under proposed regulation
HBG	High β -glucan
HBGO	High β -glucan oat bran ingredient

HBGX	High β -glucan extracted ingredient
HDL	High Density Lipoprotein
LBG	Low β -glucan
LDL	Low Density Lipoprotein
MBG	Medium β -glucan
MW	Molecular Weight
NPY	Neuropeptide Y
P293	Proposal 293
PASSCLAIM	Process for the Assessment of Scientific Support of Health Claims on Food
PYY	Peptide Y-Y
PYY ₃₋₃₆	Peptide Y-Y 3-36
RCT	Randomised Controlled Trial
RMANOVA	Repeated Measures Analysis of Variance
RTE	Ready-To-Eat
S1	Source of fibre under current regulation
S2	Source of fibre under proposed regulation
SD	Standard Deviation
TFEQ	Three Factor Eating Questionnaire
TG	Triglycerides
TIU	Trypsin Inhibitor Units
VAS	Visual Analogue Scales

PUBLICATIONS IN SUPPORT OF THIS THESIS

Published Papers

Beck, E.J, Tosh, S.M., Tapsell, L.C., Batterham, M.J. and Huang, X-F. (2009) Oat β -glucan increases postprandial cholecystokinin levels, decreases insulin response and extends subjective satiety in overweight subjects. *Molecular Nutrition and Food Research*, 53, 1343-1351.

Accepted Papers

Beck, E.J., Tapsell, L.C., Batterham, M.J., Tosh, S.M. & Huang, X. F. (2009) Increase in PYY levels following oat β -glucan ingestion is dose dependant in overweight adults. Accepted to *Nutrition Research* 22 September 2009.

Beck, E.J., Tapsell, L.C., Batterham, M.J., Tosh, S.M. & Huang, X-F. (2009) Oat β -glucan supplementation does not impact the effectiveness of an energy-restricted weight loss diet in overweight women. Accepted to *British Journal of Nutrition* 10 October 2009.

Submitted Papers

Huang, X-F., Yu, Y., Beck, E., South, T., Chen, J. Li, Y., Batterham, M., Tapsell, L. High oat β -glucan diet increases satiety via activation of the PYY3-36 -Y2 -NPY anorexigenic pathway in diet-induced obese mice. Submitted to *Journal of Cellular Biochemistry* 16 June 2009.

Published Abstracts from Oral Presentations

Beck, E.J., Tapsell, L.C., Tosh, S.M., Batterham, M.J. and Huang, X. (2009) Dietary interventions with fibre ingredients – considerations, measurements and manipulations. *Cereal Foods World*, 54(4) Supplement, A16..

Beck, E.J., Tosh, S.M., Tapsell, L.C., Batterham, M.J. and Huang, X-F. (2008) Characterisation of a functional ingredient requires multiple assessments. *Cereal Foods World*, 54(3) Supplement, A21

Beck, E.J. Tapsell, L.C., Huang, X-F. and Batterham, M.J. (2008) Relationships between 24 hour recalls and fasting measures of hunger and satiety - subjective and biochemical indices. *Nutrition and Dietetics*, 65; (S2) A11.

Beck, E.J., Norman, J.A., Batterham, M.J., Huang, X-F. and Tapsell, L.C. (2007) Dietetic Practice in Appetite Research – acute meal test studies. *Nutrition and Dietetics*, 64; Suppl.1, S49-S51.

Beck, E., Tapsell, L., Batterham, M. and Huang, X-F. Developing Foods with Fibre Effects. 2008 *International Congress of Dietetics*, Yokohama, Japan. (OS-8-1, Sept 8-11).

Huang, X.F., South, T., Beck, E., Batterham, M., Grinter, K. and Tapsell, L. (2008) Diets high in oat-derived beta -glucan promote negative energy regulatory pathway of hypothalamic NPY system in chronic diet-induced obesity in mice, *The 2008 Obesity Society Conference*, Phoenix, USA, P193.

Other Presentations from 2006-2009

Beck, E.J., Hazlewood, T., MacDonald, R. and Crockett, N. (2006) Team teaching in clinical dietetics – student feedback and student outcomes. *Nutrition and Dietetics*, 63; Suppl. 1, A57-A59.

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ABSTRACT

Making claims on the health effects of foods currently presents major challenges to nutrition science. As a case in point, oat β -glucan has been shown to deliver a number of health benefits, including an ability to lower cholesterol levels as well as reducing glucose and insulin responses to a meal. These physiological functions are related to the viscosity and solubility of the β -glucan, with the viscosity a function of concentration and molecular weight. Further, despite epidemiological evidence that high fibre diets are associated with lower levels of overweight and obesity in populations, and experimental evidence that fibre will “make you feel fuller for longer”, there is little evidence linking specific fibres with weight control. Changes to regulations governing health claims in Australia and New Zealand are currently under review, and while they reflect European and other regional positions in allowing claims for β -glucan and cholesterol, they do not address other health benefits such as weight loss. This thesis provides a novel approach to evidence based research in food by combining studies in food science, acute meal tests and longer term dietary interventions. The hypothesis examined in this thesis is that overweight individuals following a nutritionally-balanced, energy-restricted diet including oat β -glucan will experience increased satiety and lose more weight than if they followed the same diet without the added β -glucan.

Product development studies examined the effects of extrusion on the important physical attributes of β -glucan included in a ready-to-eat cereal product. It did not prove difficult to produce a cereal that maintained β -glucan at high molecular weight (>1 million) and was viscous at high concentration (up to 5g β -glucan/cereal serve). Extrusion improved solubility which means the effects of downstream processing in this manner are likely to improve the physiological effects of β -glucan in cereals.

Results of a meal-test study with fourteen subjects found that increasing doses of β -glucan up to 5.5 g, decreased insulin levels ($P=0.011$) and increased subjective satiety measured by visual analogue scales ($P=0.039$). Increasing doses of β -glucan were correlated with increased plasma concentrations of cholecystokinin (CCK) and peptide Y-Y (PYY) ($R^2=0.970$ and 0.994 respectively). Food intake at a subsequent meal was decreased with inclusion of β -glucan in the earlier test meal, although the differences were not statistically significant.

A 3-month randomised controlled trial of 66 overweight women was then conducted to investigate the effects of two different doses of β -glucan (5-6g or 8-9g) on weight loss within an energy-restricted regimen. Outcome measures included weight loss and markers of appetite regulation (hormones) as well as changes in metabolic variables related to cardiovascular disease. All groups lost weight (approximately 5% of body weight) and showed a reduced waist circumference ($P < 0.001$ for both). The study sample also showed reductions in total cholesterol, LDL, HDL, leptin, PYY, glucagon-like-peptide-1 (GLP-1) values and an increase in CCK levels. No significant differences were noted between the groups for all outcome values except fasting PYY levels ($P = 0.018$) but levels did not correlate with increasing dose.

Thus, the addition of oat β -glucan did not enhance the effect of energy restriction on weight loss in mildly overweight women, although large standard deviations in observed results, suggested that individual responsiveness makes elucidation of significant changes difficult. Adding these results to the body of evidence, it seems that some evidence exists relating to β -glucan and satiety with the most likely mechanisms relating to changes in absorption of nutrients and resultant release of anorexigenic hormones. There appears to be insufficient evidence to suggest the validity of a claim related to β -glucan and weight control. Further research of this nature would build on the knowledge of the mechanisms of satiety elucidated here, and this would further investigate how β -glucan and other soluble fibres may help weight control over longer time frames.