SHORT COMMUNICATION

Reduction in postprandial glucose excursion and prolongation of satiety: possible explanation of the long-term effects of whole grain Salba (*Salvia Hispanica L.*)

V Vuksan[1,2,3,4,5], AL Jenkins[1], AG Dias[1,3], AS Lee[1,3], E Jovanovski[1], AL Rogovik[1] and A Hanna[4,5]

[1]Clinical Nutrition and Risk Factor Modification Centre, St Michael's Hospital, Toronto, Ontario, Canada; [2]Keenan Research Center of the Li Ka Shing Knowledge Institute, St Michael's Hospital, Toronto, Ontario, Canada; [3]Department of Nutritional Sciences, Faculty of Medicine, University of Toronto, Toronto, Ontario, Canada; [4]Department of Medicine, Faculty of Medicine, University of Toronto, Toronto, Ontario, Canada and [5]Division of Endocrinology and Metabolism, St Michael's Hospital, Toronto, Ontario, Canada

Despite strong correlations linking whole-grain consumption to reductions in heart disease, the physiological mechanisms involved remain ambiguous. We assessed whether Salba (*Salvia Hispanica L.*) whole grain reduces postprandial glycemia in healthy subjects, as a possible explanation for its cardioprotective effects observed in individuals with diabetes. The study used acute, randomized, double-blind, controlled design in which 11 healthy individuals (6 males and 5 females; body mass index $22.3 \pm 2.8 \, kg/m^2$) received 0, 7, 15 or 24 g of Salba baked into white bread. Capillary samples and appetite ratings were collected over 2 h after consumption. A dose-response reduction in postprandial glycemia ($P = 0.002$, $r^2 = 0.203$) was observed with all three doses of Salba, significantly decreasing incremental areas under the curve (iAUCs) and time point-specific blood glucose ($P < 0.05$). Appetite ratings were decreased at 60 min after high, 90 min after high and intermediate and at 120 min after all treatments ($P < 0.05$). Decrease in postprandial glycemia provides a potential explanation for improvements in blood pressure, coagulation and inflammatory markers previously observed after 12-week Salba supplementation in type II diabetes.
European Journal of Clinical Nutrition (2010) **64**, 436–438; doi:10.1038/ejcn.2009.159; published online 20 January 2010

Introduction

Given the importance of consuming whole grains as a cardioprotective measure, there is increasing interest in their effects on type II diabetes. We have previously shown that consumption of 37 g/day of the oily grain *Salvia Hispanica L.* (Salba) improves cardiovascular risk factors by reducing blood pressure, inflammatory and coagulation markers in subjects with well-controlled type II diabetes (Vuksan *et al.*, 2007). Mechanistically, this may occur through Salba's ability to trigger a favorable biochemical cascade that leads to the observed changes through reductions in postprandial glycemia. To analyze this hypothesis we studied the acute effect of escalating doses of Salba on glycemia and satiety.

Subjects and methods

A total of 11 healthy individuals (6 males and 5 females; age 30 ± 3.6 years; body mass index $22.2 \pm 1.3 \, kg/m^2$) participated in this study. Subjects with gastrointestinal/metabolic diseases or who were taking potential postprandial metabolism-altering supplements were excluded. The study was approved by the research ethics board of St Michael's Hospital. Written informed consent was obtained from all subjects.

A double-blind, placebo-controlled, randomized, crossover design was used. Participants attended the clinic on five mornings, separated by at least 48 h, after a 10- to 12-h fast.

Finger-prick capillary blood and subjective appetite ratings were collected in the fasting state and at 15, 30, 45, 60, 90 and 120 min after meal.

Salba is a brand name used to describe two registered white varieties, Sahi Alba 911 and 912, that are the result of selective breeding from the black grain *Salvia Hispanica L.* (also popularly called Chia) by the Peruvian company Agrisalba S.A. Salba has a nutrient profile that is approximately 20% higher than generic or regular Chia. In addition, the nutrient profile of Salba is highly standardized, which allows for a high degree of reproducibility. Experimental meals contained 50 g available carbohydrate with addition of 0, 7, 15 or 24 g of Salba (Salba Smart Natural Products, Denver, CO, USA), which was ground by micro-slicing rather than the crushing method (to reduce rancidity) and baked into white bread in a Black & Decker All-In-One Pro Breadmaker (The Black & Decker Corporation, Towson, MD, USA) according to standard recipes. Energy value and macronutrient compositions of test and control breads are shown in Table 1. Control white bread was consumed twice and the results were averaged.

Capillary blood samples were analyzed using the glucose-oxidase method (YSI 2300 STAT Analyzer, Yellow Springs, OH, USA). Satiety was assessed using four questions with opposing statements at each end of 100 mm visual analog scale (How full do you feel? How strong is your desire to eat? How hungry do you feel? How much do you think you could

eat right now?). Appetite rating was calculated from these four questions (Blundell and Rogers, 1991).

Statistical analysis

Incremental areas under the curve (iAUCs) for blood glucose and for the average appetite ratings were calculated geometrically using the trapezoid rule (Wolever *et al.*, 1991). Statistical analysis was performed using NCSS-2000 (NCSS, Kaysville, UT, USA). Results were expressed as mean $\pm$ s.d. and significance was set at $P < 0.05$. Statistical analysis was conducted after a comparison of the sampling distribution to a normal distribution (Shapiro–Wilk and Kolmogorov–Smirnov tests). Pearson's correlations and linear regression analysis were used to determine dose-response relationships for glucose and appetite iAUCs. Two-way analysis of variance was performed with the glucose values and appetite scores at each time point with *post hoc* assessment using the Neuman–Keuls method to adjust for multiple comparisons.

Results

Compared with control, the percentage of reductions in mean iAUCs for blood glucose were 41, 28 and 21% after high, intermediate and low Salba doses, respectively ($P < 0.05$; Table 2). Furthermore, significantly lower blood glucose levels were observed after the high dose at 30, 45 and 60 min, intermediate at 60 min and low dose at 45 min ($P < 0.05$) compared with control. Linear regression analysis showed glucose iAUCs to be significantly associated with the Salba dose ($P = 0.002$; $r^2 = 0.203$; $r = 0.45$).

Appetite ratings were decreased when compared with control at 60, 90 and 120 min after the high dose, at 90 and 120 min after the intermediate and at 120 min after the low dose ($P < 0.05$; Table 2). Incremental AUC appetite ratings decreased by 63, 58 and 41% after high, intermediate and low doses but this did not reach significance. Significant

Table 1 Energy value and macronutrient compositions of test and control breads

Parameter	Control	Low dose	Intermediate dose	High dose
Energy value (kcal)	245	277	314	355
Fat (g)	0.7	3.1	5.7	8.7
Carbohydrates (g)	52.1	54.9	58.1	61.7
Available carbohydrates (g)	50.0	50.0	50.0	50.0
Fiber (g)	2.1	4.9	8.1	11.7
Protein (g)	9.4	11.1	13.1	15.3

Table 2 Incremental changes and iAUCs for postprandial blood glucose and appetite after high, intermediate, and low dose, and control treatments ($n = 11$)[a]

	Treatment	15 min	30 min	45 min	60 min	90 min	120 min	iAUC
Incremental blood glucose (mmol/l)	High dose	0.42 ± 0.31	1.52 ± 0.45[b]	1.35 ± 0.50[b]	0.82 ± 0.43[b]	0.44 ± 0.61	0.49 ± 0.34	89.5 ± 16.7[b]
	Int. dose	0.76 ± 0.57	1.61 ± 0.57	1.57 ± 0.93	0.97 ± 0.55[b]	0.76 ± 0.35	0.42 ± 0.37	110.1 ± 26.4[b]
	Low dose	0.52 ± 0.49	1.85 ± 0.83	1.62 ± 0.75[b]	1.16 ± 0.63	0.91 ± 0.55	0.46 ± 0.45	120.8 ± 39.2[b]
	Control	0.71 ± 0.53	2.10 ± 0.64	2.18 ± 0.94	1.64 ± 0.96	1.07 ± 0.90	0.58 ± 0.64	152.3 ± 71.4
Incremental appetite rating (mm)	High dose	−37 ± 26	−42 ± 23	−44 ± 20	−44 ± 23[b]	−42 ± 22[b]	−36 ± 21[b]	−4662 ± 2285
	Int. dose	−40 ± 21	−42 ± 20	−43 ± 24	−40 ± 25	−40 ± 23[b]	−35 ± 25[b]	−4520 ± 2509
	Low dose	−42 ± 22	−40 ± 23	−36 ± 17	−35 ± 19	−32 ± 22	−32 ± 19[b]	−4029 ± 2028
	Control	−32 ± 18	−29 ± 18	−27 ± 19	−24 ± 22	−20 ± 22	−16 ± 23	−2861 ± 2009

Abbreviations: iAUC, incremental area under the curve; Int., intermediate.
[a]Data are mean ± s.d. IAUCs are expressed in min mol/l for blood glucose and in min mm for appetite.
[b]Significantly different from the control group ($P < 0.05$).

correlation between incremental blood glucose and incremental appetite values was observed ($P < 0.001$; $r = 0.32$).

Discussion

These preliminary data suggest that ingestion of escalating doses of Salba attenuate postprandial glycemia in a dose-dependent manner in healthy subjects. On average, each gram of Salba baked in the white bread reduced postprandial glycemia by 2% compared with the control. Reductions in postprandial glycemia observed after Salba are not dissimilar to those observed with acarbose (Shimabukuro *et al.*, 2006) despite different mechanisms of action. Interestingly, acarbose showed similar long-term effects on blood pressure, coagulation and inflammation (Chiasson *et al*, 2003; Chiasson, 2006) as observed with Salba (Vuksan *et al.*, 2007), supporting the hypothesis that long-term benefits observed with both may be achieved through attenuating postprandial glycemia. Furthermore, both may affect signals of satiety, as showed by the prolongation of satiety observed with Salba and an increase in satiety gut hormones by acarbose (Gentilcore *et al.*, 2005).

Despite small sample size, this number has been shown to provide a reasonable degree of power and precision when measuring postprandial glycemia (Brouns *et al.*, 2005). Similarly, although this study included only healthy individuals it may nevertheless apply to individuals with diabetes, as hyperglycemia is an independent predictor of future cardiovascular events in both healthy and diabetic individuals (Coutinho *et al.*, 1999).

The simultaneous attenuation of both postprandial glycemia and prolongation of satiety by Salba can be explained by the reduction in the rate of nutrient delivery from the stomach to the small intestine, and concurrently providing continuous and more extended signals to the gut receptors, affecting after-meal satiety levels and ingestion sensory factors (Read *et al.*, 1994). High levels of dietary fiber, calcium, magnesium and antioxidant capacity of Salba are likely to be the main triggers of these effects.

The importance of controlling postprandial glycemia is supported by the observation that postprandial glucose excursion independently activates homeostasis of thrombotic-prone conditions, mediated by transient overproduction of reactive oxygen species (Monnier *et al.*, 2006). These free radicals induce a biochemical cascade resulting in increased inflammation, hypercoaguability and endothelial dysfunction that favors vasoconstriction and elevation of blood pressure, leading to diabetes and early cardiovascular disease (Ceriello *et al.*, 1996; Monnier *et al.*, 2006; O'Keefe and Bell, 2007; O'Keefe *et al.*, 2008). Improvements in postprandial glycemia and the increase in satiety observed in this study can at least in part offer explanation for reductions in blood pressure, inflammatory and coagulation factors observed in our longer-term study with Salba (Vuksan *et al.*, 2007).

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

References

Blundell JE, Rogers PJ (1991). Hunger, hedonics, and the control of satiation and satiety. In: Friedman MI, Tordoff MG, Kare MR (eds). *Chemical Senses, Vol IV. Appetite and Nutrition*. Marcel Dekker: New York. pp 127–148.

Brouns F, Bjorck I, Frayn KN, Gibbs AL, Lang V, Slama G *et al.* (2005). Glycaemic index methodology. *Nutr Res Rev* **18**, 145–171.

Ceriello A, Taboga C, Tonutti L, Giacomello R, Stel L, Motz E *et al.* (1996). Post-meal coagulation activation in diabetes mellitus: the effect of acarbose. *Diabetologia* **39**, 469–473.

Chiasson JL (2006). Acarbose for the prevention of diabetes, hypertension, and cardiovascular disease in subjects with impaired glucose tolerance: the Study to Prevent Non-Insulin-Dependent Diabetes Mellitus (STOP-NIDDM) Trial. *Endocr Pract* **12** (Suppl 1), 25–30.

Chiasson JL, Josse RG, Gomis R, Hanefeld M, Karasik A, Laakso M (2003). Acarbose treatment and the risk of cardiovascular disease and hypertension in patients with impaired glucose tolerance: the STOP-NIDDM trial. *JAMA* **290**, 486–494.

Coutinho M, Gerstein HC, Wang Y, Yusuf S (1999). The relationship between glucose and incident cardiovascular events. A metaregression analysis of published data from 20 studies of 95 783 individuals followed for 12.4 years. *Diabetes Care* **22**, 233–240.

Gentilcore D, Bryant B, Wishart JM, Morris HA, Horowitz M, Jones KL (2005). Acarbose attenuates the hypotensive response to sucrose and slows gastric emptying in the elderly. *Am J Med* **118**, 1289.

Monnier L, Mas E, Ginet C, Michel F, Villon L, Cristol JP *et al.* (2006). Activation of oxidative stress by acute glucose fluctuations compared with sustained chronic hyperglycemia in patients with type 2 diabetes. *JAMA* **295**, 1681–1687.

O'Keefe JH, Bell DS (2007). Postprandial hyperglycemia/hyperlipidemia (postprandial dysmetabolism) is a cardiovascular risk factor. *Am J Cardiol* **100**, 899–904.

O'Keefe JH, Gheewala NM, O'Keefe JO (2008). Dietary strategies for improving post-prandial glucose, lipids, inflammation, and cardiovascular health. *J Am Coll Cardiol* **51**, 249–255.

Read N, French S, Cunningham K (1994). The role of the gut in regulating food intake in man. *Nutr Rev* **52**, 1–10.

Shimabukuro M, Higa N, Chinen I, Yamakawa K, Takasu N (2006). Effects of a single administration of acarbose on postprandial glucose excursion and endothelial dysfunction in type 2 diabetic patients: a randomized crossover study. *J Clin Endocrinol Metab* **91**, 837–842.

Vuksan V, Whitham D, Sievenpiper JL, Jenkins AL, Rogovik AL, Bazinet RP *et al.* (2007). Supplementation of conventional therapy with the novel grain Salba (Salvia hispanica L.) improves major and emerging cardiovascular risk factors in type 2 diabetes: results of a randomized controlled trial. *Diabetes Care* **30**, 2804–2810.

Wolever TM, Jenkins DJ, Jenkins AL, Josse RG (1991). The glycemic index: methodology and clinical implications. *Am J Clin Nutr* **54**, 846–854.