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Phaseolus beans: impact on glycaemic response and chronic disease risk in human subjects

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Abstract

Consumption of *Phaseolus vulgaris* bean species such as pinto, black, navy or kidney may be beneficial in the prevention and treatment of chronic diseases. In particular, conditions that are promoted by increased glycaemic stress (hyperglycaemia and hyperinsulinaemia) including diabetes, CVD and cancer seem to be reduced in individuals who eat more of these beans. The present paper discusses the influence of *P. vulgaris* species on glycaemic response and the impact that relationship may have on the risk of developing diabetes, CVD and cancer.

Key words: *Phaseolus vulgaris*: Beans: Glycaemic response: Chronic disease: Human subjects

Consumption of the *Phaseolus vulgaris* species of beans may be beneficial in the prevention and treatment of chronic diseases that are promoted by increased glycaemic stress (hyperglycaemia and hyperinsulinaemia). These conditions include diabetes and CVD, as well as cancer.

The importance of controlling postprandial blood glucose in the prevention and management of chronic disease has gained recognition in recent years[1–3]. Glucose elevations cause oxidative stress that then alters the ability of the lining of blood vessels, or endothelium, to respond appropriately to blood flow. Some foods such as beans appear to stabilise or reduce postprandial glucose variability. Epidemiological studies show associations with increased legume consumption and decreased rates or prevalence of chronic diseases such as type 2 diabetes mellitus (T2DM)[4–6]. Most beans such as the common bean (*P. vulgaris* sp., for example, pinto bean, black bean, navy bean) have a low glycaemic index (GI)[7,8]. In contrast, high-GI items such as white rice and white bread can elevate postprandial glucose and result in increased oxidative stress[9–11].

The low glycaemic response of beans alone has been documented[9,12], but few studies have looked at the acute effects of *P. vulgaris* or common beans on glycaemic response as part of a meal[8,13]. In the limited number of studies that have looked at mixed meals, beans combined with a high-GI or refined carbohydrate food produced a glycaemic response that was in between the GI of the two foods when analysed alone[8,13,14]. It is not clear what kind of synergistic effects are produced or if an intermediate value always exists when the composition of the foods is varied. These findings are important for guiding recommendations to improve diabetes control and lower CVD and cancer risk[10]. It is possible that adding a low-GI food may reduce damage produced by other high-GI components of that meal. One important consideration is that we do not know the magnitude of the effect. It also appears that the glycaemic response attenuation is not necessarily linear.

The present paper discusses the relationship between glycaemic concentrations and glycaemic response produced by the consumption of *P. vulgaris* species, and the impact that relationship may have on the risk of developing diabetes, CVD and cancer. Glycaemic concentration refers to blood glucose measures at a particular point in time (for example, fasting) and glycaemic response is defined as blood glucose

Abbreviations: GI, glycaemic index; GL, glycaemic load; T2DM, type 2 diabetes mellitus.

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concentration following meal consumption, which is established by the rate at which glucose is released into and subsequently removed from circulation[15].

Review methods

The electronic databases MEDLINE®, CINAHL® and the Cochrane Library were searched in November 2010, May 2011 and August 2011 with no date limitations. Keywords used for the search were '*Phaseolus vulgaris*', 'beans', 'legumes' and 'glycaemic response'. Abstracts of articles identified as potentially relevant based on the use of the terms *Phaseolus vulgaris*, *beans*, or *legumes* and *glycaemic response* in the abstract or keywords were obtained. The 1438 article abstracts were then reviewed to determine if the article investigated the impact of *P. vulgaris* on glycaemic response or the prevention or treatment of diabetes mellitus, heart disease, CVD, obesity, weight management or cancer. Relevant articles (*n* 118) were then collected in full text.

The full-text articles were screened for inclusion based on the following criteria: (1) published in a scientific peer-reviewed journal; (2) used *P. vulgaris* as a sole treatment or as part of a treatment; (3) published in English; (4) addressed the impact of *P. vulgaris* on glycaemic response or prevention or treatment of diabetes mellitus, CVD or cancer; (5) used human subjects; and (6) not an editorial, expert opinion, review or instructive article. The reference lists of included articles, review articles and meta-analyses were hand-searched for articles that met the inclusion criteria but that had not been identified during the electronic database search. Relevant articles from the reference lists that met the inclusion criteria were collected in full text. We found twenty-three articles meeting the criteria for inclusion in the tables in the present review.

Evidence for health outcomes

Evidence that beans induce low glycaemic response

Beans and other dry grain pulses typically reduce postprandial glucose elevations in short-term studies with non-diabetic and diabetic individuals compared with most starch foods[13,14,16–23]. Most studies that examined the impact of legumes on glycaemic control have utilised either normoglycaemic or T2DM participants.

The lower glycaemic response to beans has been attributed to their low GI or delayed digestion of the carbohydrate within and, therefore, delayed absorption of glucose[7,8,10,12–14]. One important question to address, however, is determination of the magnitude and nature of the effect of beans on the glycaemic response to meals containing high-GI foods. The few studies that have explored this question generally report that beans combined with a high-GI food produce a glycaemic response that is intermediate between the high- and low-GI foods, but this is not to say that the nature of the effect is additive or linear[8,13,14,17,19–22].

The mixed-meal findings presented in Table 1 have important implications for chronic disease risk reduction[10,24]. Individuals generally consume foods in combination, not in isolation, so determining the overall glycaemic response to the combination of foods has greater 'real-life' application to determining chronic disease risk reduction. Demonstrating that inclusion of beans in a meal results in a lower glycaemic response to the meal will provide a realistic, food-based mechanism for reducing the oxidative stress, endothelium-dependent vasodilation, and increased blood pressure associated with increased risk for some chronic diseases such as T2DM, complications of T2DM and CVD. Further research is required to examine the lower glycaemic response associated with bean meals along with changes in oxidative stress, endothelium-dependent vasodilation and blood pressure to confirm the validity and strength of this relationship. These studies should be adequately powered randomised controlled trials lasting at least 6 weeks in order to effectively assess the impact of beans' ability to lower the glycaemic response on these markers for chronic disease risk.

Impact of Phaseolus vulgaris *species and glycaemic response on type 2 diabetes mellitus and risk factors for type 2 diabetes mellitus*

Controlling postprandial glucose increases through incorporation of low-GI foods such as *P. vulgaris* sp. has a favourable impact on glucose control. Studies demonstrating that consumption of low-GI foods such as beans improve glucose control and T2DM control, as well as reduce risk for developing T2DM, have been analysed and summarised elsewhere and will be covered briefly in the present review[25–27]. A recent Cochrane review assessed eleven randomised controlled trials and determined the effects of low-GI or low-glycaemic load (GL) diets and found that they improve glycaemic control in individuals with diabetes[28]. Their positive conclusions are supported by other meta-analyses[29,30] which demonstrated reductions in HbA1c of 0·27 (95 % CI −0·5, −0·03)[30] to 0·43 (95 % CI 0·13, 0·72)[29] when low-GI diets were compared with high-GI diets. The reductions in HbA_{1c} achieved with a low-GI diet are comparable with those produced by pharmacological interventions (for example, hypoglycaemic medications)[29]. However, the studies included in these reviews treated low-GI, or low-GL, diets in a more global fashion and did not focus solely on beans.

A meta-analysis[7] examined forty-one studies that examined the effects of legume consumption alone, legume consumption as part of a low-GI diet, and legume consumption as part of a high-fibre diet. Pooled analyses demonstrated that legumes, alone or in low-GI or high-fibre diets, improve markers of longer-term glycaemic control (HbA_{1c} and fructosamine). Of the reports from the meta-analysis[7] that focused on *P. vulgaris* consumption, seven[31–37] are summarised in Table 2. These results are encouraging news for individuals with or at risk for T2DM since they indicate that simple diet changes, such as the inclusion of beans, can have a positive impact on glycaemic control. Nevertheless, these studies also illustrate the fact that few studies have focused on how bean intake influences risk factors for or the treatment of T2DM, let alone whether their effect is linked solely to the lower

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Table 1. Impact of *Phaseolus vulgaris* species on glycaemic response

Study reference	Design	Sample size	Population	Duration	Treatment	Results	Conclusions
(1) GI studies with the same amount of carbohydrate in test food as control							
(a) Whole beans							
Bornet *et al.* (1987)[13]	Randomised cross-over trial	Eighteen adults	Men and women with T2DM	Six test meals consumed on separate days	Test foods: White bread White rice Wheat flour spaghetti Kidney beans Lentils Potato flakes Foods consumed alone or as part of iso-glucido-lipido-protidic meal All foods and meals provided 50 g available carbohydrate	GI of single foods: White bread > potato flakes > wheat flour spaghetti > white rice > lentils > kidney beans ($P<0{\cdot}001$) GI of test meals: White bread > potato flakes > white rice > wheat flour spaghetti > lentils > kidney beans ($P<0{\cdot}001$) No significant differences between test foods alone and test foods as part of a meal	GI remains discriminating even in the context of a mixed meal in this population
(2) Single-meal postprandial studies							
(a) Whole beans							
Jenkins *et al.* (1980)[16]	Randomised controlled cross-over trial	Groups of between five and ten adults	Healthy men and women	Eight legumes and twenty-four foods consumed on separate days	Thirty-two foods: Beans: Butter beans Haricot beans Kidney beans Soyabeans Blackeye peas Chickpeas Marrowfat peas Lentils Tubers: Instant mashed potatoes New potato Sweet potato Yams Grains: Buckwheat Millet Brown rice White rice Sweetcorn Bread and pastas: White bread Wholemeal bread White spaghetti Brown spaghetti Ryvita Breakfast cereals: All-Bran Cornflakes Muesli Porridge oats Shredded Wheat Weetabix Biscuits: Digestive Oatmeal	Mean glucose AUC and peak rise after bean consumption were, respectively, 51 % ($P<0{\cdot}001$) and 41 % ($P<0{\cdot}001$) of the values after the grains; 51 % ($P<0{\cdot}01$) and 45 % ($P<0{\cdot}001$) of the values after the bread and spaghetti; 45 % ($P<0{\cdot}001$) and 43 % ($P<0{\cdot}001$) of the values after the biscuits; 51 % ($P<0{\cdot}001$) and 48 % ($P<0{\cdot}001$) of the values after the breakfast cereals; and 55 % ($P<0{\cdot}01$) and 45 % ($P<0{\cdot}001$) of the values after the tubers	Leguminous seeds as a class produce the lowest rise in postprandial blood glucose of the carbohydrate-rich foods tested

Table 1. *Continued*

Study reference	Design	Sample size	Population	Duration	Treatment	Results	Conclusions
					Rich tea Water Fresh peas Baked beans Canned soyabeans		
Panlasigui *et al.* (1995)[18]	Randomised cross-over trial	Eleven adults	Healthy men and women, aged 22 ± 1·1 years	Six meals consumed on separate days	Test foods: Chickpeas Pigeon peas Black beans Mung beans White beans White bread (control) Each meal provided 50 g available carbohydrate	Glycaemic response to all beans was lower compared with white bread ($P<0·01$). Glycaemic response to chickpeas ($P<0·01$) and the GI of chickpeas ($P<0·01$) were lower than to black beans, pigeon peas and mung beans but not different from white beans	The differences in the glycaemic responses among the legumes could be due to the differences in amount and kind of dietary fibre, amylose content and the presence of antinutrients
Thompson *et al.* (2009)[14]	Randomised cross-over trial	Nine adults	Healthy adult women	Three test meals consumed on separate days	Test meals: White rice Black beans/rice Chickpeas/rice Each meal provided 50 g available carbohydrate	Net changes in glucose responses were significantly lower for the black beans/rice and chickpeas/rice meals than the rice control at 60 and 90 min post-treatment ($P=0·041$ and $P=0·002$, respectively)	Black bean and chickpea intake as part of a meal can reduce the glycaemic response to a high-GI food
Thompson *et al.* (2011)[21]	Randomised cross-over trial	Seventeen adults	Adults with T2DM	Four test meals consumed on separate days	Test meals: White rice Pinto beans/rice Black beans/rice Dark red kidney beans/rice Each meal provided 50 g available carbohydrate	Net changes in glucose responses were significantly lower for the pinto beans/rice, black beans/rice and dark red kidney beans/rice meals than the rice control at 90, 120 and 150 min post-treatment ($P<0·05$) IAUC were also significantly reduced for the pinto beans/rice ($P<0·01$) and black beans/rice ($P<0·05$) meals compared with the rice control	The combination of whole beans and rice may be beneficial to those with T2DM to assist with blood glucose management
(b) Other forms of beans							
Leathwood & Pollet (1988)[17]	Randomised double-blind cross-over trial	Trial 1: six adults Trial 2: six adults	Trial 1: healthy men and women, aged 30–45 years Trial 2: healthy men and women, aged 35–45 years	Single meals consumed on separate days Trial 1: three meals Trial 2: six meals	Trial 1: Bean flakes or potato flakes as part of a shepherd's pie Trial 2: Bean flakes or potato flakes as part of a shepherd's pie with a spinach, ratatouille or tomato topping	Trial 1: The meal with bean flakes produced a lower 30 min postprandial rise in glucose compared with the potato flake meal ($P<0·01$) Trial 2: The meals with bean flakes produced a greater feeling of fullness, less hunger and less desire for a snack at 240 min postprandially ($P<0·05$, $P<0·05$ and $P<0·05$, respectively)	'Slow-release carbohydrates' in the form of bean flakes, when included in a realistic meal, produce a low, sustained rise in plasma glucose concentrations and a delay in the reappearance of rated hunger
Potter *et al.* (1981)[19]	Randomised cross-over trial	Eight adults	Healthy men, aged 22–45 years	Four meals consumed on separate days	Four blended test meals: Liquid glucose Brown rice Pinto beans All Bran Each meal provided 75 g carbohydrate	Pinto bean meals produced a lower 30, 60 and 180 min postprandial rise in glucose ($P<0·01$, $P<0·05$ and $P<0·01$, respectively) compared with the liquid glucose meal and a lower 30 min postprandial rise in insulin ($P<0·01$) compared with the liquid glucose meal and the rice meal	Meals containing the same amount of carbohydrate produce different responses in glucose and insulin
Tappy *et al.* (1986)[20]	Randomised cross-over trial	Ten adults	Six healthy men and women, aged 19–37 years Four obese adults with	Two meals consumed on separate days	Test meals: White bean flakes meal Potato flakes meal Each meal provided 50 g carbohydrate	Postprandial glucose and insulin concentrations were lower with the bean flakes meal compared with the potato flakes meal at 30 min ($P<0·01$ and $P<0·001$, respectively) in the healthy participants At 150 and 180 min postprandially, glucose	The reduced but more prolonged elevations of glucose and insulin are consistent with a slower digestion rate of starch and a delay in glucose

Table 1. *Continued*

Study reference	Design	Sample size	Population	Duration	Treatment	Results	Conclusions
			T2DM, aged 48–61 years			($P<0·02$ and $P<0·05$, respectively) and insulin concentrations ($P<0·05$ and $P<0·05$, respectively) were higher with the bean flakes meal compared with the potato flakes meal in the healthy participants Statistical analyses were not performed on the results from the obese diabetic participants	absorption
Torsdottir *et al.* (1989)[22]	Randomised cross-over trial	Six adults	Healthy men, aged 22–30 years	Two test meals consumed on separate days	Test meals: Mashed bean flakes and meat Mashed potato flakes and meat	Bean flakes meal produced lower blood glucose ($P<0·01$) and serum insulin ($P<0·05$) concentrations than the potato flakes meal IAUC was lower following the bean flakes meal ($P<0·05$) compared with the potato flakes meal No significant difference in gastric emptying between the two meals	Low glycaemic response after a meal containing bean flakes may be due to slow digestion of bean starch in the small intestine
Tovar *et al.* (1992)[23]	Randomised cross-over trial	Ten adults	Healthy men and women, aged 36 ± 2·5 years	Six test meals consumed on separate days	Test meals: Red beans Boiled beans Autoclaved beans Bean precooked flour porridge Bean flour with free starch cakes Lentils Lentil precooked flour porridge Wheat bread Each meal provided 30 g available carbohydrate	All meals containing legumes produced lower postprandial glucose values at 30 and 45 min ($P<0·05$) compared with the wheat bread meal. All meals containing legumes produced lower postprandial insulin values at 30 and 45 min ($P<0·05$) compared with the wheat bread meal. Processed bean meals (bean precooked flour porridge and bean flour with free starch cakes) produced glucose and insulin responses that were higher than the whole bean meals but lower than the wheat bread meals ($P<0·05$)	Results from this study confirm the deleterious effect of processing on the metabolic responses to legumes. This may be attributed in part to thermal and/or mechanical alteration of the botanical structure of the seeds and also to the release of physically inaccessible starch by mechanical disruption of cell walls
Winham *et al.* (2007)[8]	Randomised cross-over trial	Twelve adults: low-dose treatment Eleven adults: high-dose treatment	Healthy men and women, aged 20–65 years	Six test meals (three low-dose, three high-dose) consumed on separate days	Low-dose meals (included half cup bean paste): Pinto beans Black-eyed pea Navy beans High-dose meals (included one cup bean paste): Pinto beans Black-eyed pea Navy beans	No significant differences by dose or bean type in glucose, insulin response, whole-body insulin sensitivity or HOMA	When provided in the form of a spread (bean paste), pinto bean, navy bean, or black-eyed pea intake as part of a treatment did not significantly reduce glycaemic response to high-GI foods

T2DM, type 2 diabetes mellitus; GI, glycaemic index; AUC, area under the curve; IAUC, incremental area under the curve; HOMA, homeostasis model assessment.

Table 2. *Phaseolus vulgaris* species, glycaemic response and type 2 diabetes mellitus and CVD risk

Study reference	Design	Sample size	Population	Duration	Treatment	Results	Conclusions
Anderson *et al.* (1984)[31]	Randomised parallel trial	Nine adults on oat-bran diet Ten adults on bean diet	Hypercholesterolaemic men, aged 34–66 years	7 d on control diet followed by 21 d on test diet	Oat-bran diet contained 100 g oat bran per d Bean diet contained 115 g dried pinto and navy beans per d	Oat-bran and bean diets both lowered fasting plasma glucose concentrations in hypertriacylglycerolaemic subjects ($P<0.02$). There was no significant difference between the diets Oat-bran and bean diets both lowered serum cholesterol levels ($P<0.0005$) and LDL-cholesterol levels ($P<0.0005$ oat-bran and $P<0.0025$ bean). There was no significant difference between the diets	Oat-bran and bean diets had a favourable impact on total and LDL-cholesterol concentrations in hypercholesterolaemic men Oat-bran and bean diets lowered fasting plasma glucose concentrations in hypertriacylglycerolaemic men. However, this study did not explore the potential relationship between the improvement in glucose concentrations and the hypocholesterolaemic effect of the diets
Bazzano *et al.* (2001)[4]	Cohort	9632 adults Cases: 1802 CHD and 3680 CVD	Men and women who participated in the First National Health and Nutrition examination Survey Epidemiologic Follow-up Study with no CVD at baseline	Average 19 years of follow-up	None; frequency of legume intake was estimated using a 3-month FFQ	Legume consumption inversely associated with risk of CHD ($P=0.002$ for trend) and CVD ($P=0.02$ for trend) after adjustment for established CVD risk factors Consuming legumes four or more times each week compared with less than one time per week associated with 22 % lower risk of CHD (RR = 0·78; 95 % CI 0·68, 0·90) and 11 % lower risk of CVD (RR = 0·89, 95 % CI 0·80, 0·98)	Legume intake, estimated using an FFQ, is inversely related to risk of CHD and CVD This study did not address the role that legumes' influence on glycaemic response might play in the CHD and CVD risk reduction
Cobiac *et al.* (1990)[32]	Randomised cross-over trial	Twenty adults	Mildly hypercholesterolaemic men, aged 29–65 years	4 weeks per intervention	Low-fibre diet with one meal replaced by: 440 g canned baked beans daily or 440 g canned spaghetti daily	Neither the baked bean nor spaghetti treatment significantly altered total, HDL- or LDL-cholesterol, TAG or glucose concentrations	This study found that baked bean consumption did not have an impact on risk factors for CVD or T2DM The study did not assess the impact of glycaemic response on total, HDL- or LDL-cholesterol concentrations
Fleming & Shaheen (1988)[33]	Randomised cross-over trial	Six adults	Healthy men, aged 21–32 years	8 d per intervention	Controlled diet with: Dark red kidney beans daily or Bran cereal daily Total weight of food provided in proportion to body weight	Insulin responses on days 1 and 7 were lower following bean consumption ($P\leq0.02$) Glucose and insulin responses were both lower on day 7 compared with day 1 following both bean and bran cereal consumption ($P\leq0.05$) The postprandial insulin concentrations following lunch were higher after consumption of the bean breakfast ($P=0.03$)	Consumption of a high-fibre breakfast containing either dark red kidney beans or bran cereal reduced postprandial insulin and glucose responses after 7 d Consumption of dark red kidney beans reduced postprandial insulin after breakfast, but increased postprandial insulin after lunch The study did not assess the impact of glycaemic response on long-term risk for chronic disease
Jang *et al.* (2001)[34]	Randomised parallel controlled trial	Seventy-six adults	Hypercholesterolaemic and/or hypertriacylglycerolaemic men, aged 58·4 ± 1·53 (control) and 54·8 ± 1·20 (whole grain/legume) years	4-week run-in on usual diet 16-week intervention	Control diet: usual diet containing cooked refined rice Intervention diet: 70 g whole grain/legume powder (22·2 % black beans) replacing cooked refined rice for breakfast daily	HDL-cholesterol concentrations increased with the whole grain/legume powder intervention ($P=0.001$) Glucose, malondialdehyde, 8-epi-PGF$_{2\alpha}$, and homocysteine concentrations decreased with the whole grain/legume powder intervention ($P=0.000$, $P=0.028$, $P=0.003$ and $P=0.032$, respectively) OGTT revealed nine subjects in the control group and twelve subjects in the whole grain/legume powder group had	Consumption of a whole grain/legume powder reduced multiple risk factors for chronic disease and increased HDL-cholesterol concentrations The study did not assess whether the impact of the whole grain/legume powder on glycaemic response influenced the other risk factor modifications reported

Table 2. *Continued*

Study reference	Design	Sample size	Population	Duration	Treatment	Results	Conclusions
						new-onset T2DM In non-diabetic subjects, whole grain/legume powder consumption decreased fasting glucose, response areas of glucose and insulin during OGTT, and insulin resistance In the T2DM subjects, whole grain/legume powder consumption decreased fasting glucose and the response area of glucose during OGTT	
McAuley *et al.* (2002)[104]	Randomised parallel trial	Seventy-nine adults	Normoglycaemic insulin-resistant men and women	4 months	Modest diet and exercise programme Intensive diet and exercise programme (included recommendation for legume consumption) Control group	Intensive diet and exercise programme group improved insulin sensitivity (25 % increase, $P=0{\cdot}006$ *v.* 9 % in the modest group, $P=0{\cdot}23$)	This study indicated that intensive diet and exercise therapy may be required to improve insulin sensitivity in insulin-resistant adults Legumes were recommended as part of the intensive diet and exercise programme, but this study did not directly address the influence of the legumes on glycaemic response and how that may have altered insulin sensitivity
Winham *et al.* (2007)[36]	Randomised cross-over controlled trial	Sixteen adults	Hyperinsulinaemic men (*n* 7) and women (*n* 9), aged 22–65 years	8 weeks per intervention	Control: Half cup canned carrots daily Interventions: Half cup canned pinto beans daily Half cup canned black-eyed peas daily	Consumption of half cup pinto beans decreased total and LDL-cholesterol concentrations ($P=0{\cdot}011$ and $P=0{\cdot}013$, respectively) HDL-cholesterol, TAG, hs-CRP, glucose, insulin and HbA_{1c} were not significantly different	Daily pinto bean consumption decreased total and LDL-cholesterol concentrations in this study Since glucose, insulin and HbA_{1c} values were not significantly altered, this study does not indicate that the influence of beans on glycaemic response was related to the change in cholesterol concentrations
Winham & Hutchins (2007)[35]	Randomised cross-over controlled trial	Twenty-three adults	Hypercholesterolaemic men (*n* 10) and women (*n* 13), aged 22–70 years	8 weeks per intervention	Control: half cup canned carrots daily Intervention: half cup vegetarian baked beans daily	Consumption of half cup baked beans decreased total cholesterol concentrations ($P=0{\cdot}01$) LDL-cholesterol, HDL-cholesterol, TAG, hs-CRP, glucose, insulin and HbA_{1c} were not significantly different	Daily baked bean consumption decreased total cholesterol concentrations in this study Since glucose, insulin and HbA_{1c} values were not significantly altered, this study does not indicate that the influence of beans on glycaemic response was related to the change in cholesterol concentrations
Wursch *et al.* (1988)[37]	Randomised cross-over controlled trial	Six adults	Healthy young men, aged 26 ± 6 years	7 d per test meal (breakfast)	Control: 58 g glucose in 150 ml water Test meals (breakfast): 114 g white kidney bean flakes daily or 62 g potato flakes, 38·5 g low-starch wheat bran and 17 g soya isolate daily	Mean area under the glucose response curve at 1 and 2 h was higher following the potato flake-based test meal compared with the bean flake test meal ($P<0{\cdot}01$ and $P<0{\cdot}05$, respectively) Mean area under the insulin response curve at 1, 2 and 6 h was higher following the potato flake-based test meal compared with the bean flake test meal ($P<0{\cdot}01$, $P<0{\cdot}01$ and $P<0{\cdot}02$, respectively)	A breakfast containing bean flakes favourably altered postprandial glucose and insulin response curves Since this was a short-term study, the influence of the favourable postprandial effects of bean flakes on risk for chronic disease was not assessed

RR, relative risk; T2DM, type 2 diabetes mellitus; OGTT, oral glucose tolerance test; hs-CRP, high-sensitivity C-reactive protein.

glycaemic response when consumed. Studies that explore how beans exert their influence on T2DM prevention and treatment and whether their effect on glycaemic response is related to that influence are required.

Impact of Phaseolus vulgaris *species and glycaemic response on CVD and CVD risk factors*

Besides controlling postprandial glucose increases, numerous research studies indicate that a low-GI diet may also play a role in reducing the risk for or preventing CVD; however, these studies did not focus on beans as a low-GI food. These studies have been analysed and summarised elsewhere[25,26,38–40] and so will not be covered in detail in the present review. Despite the interest in the role of a low-GI diet in CVD risk reduction, the mechanisms behind this risk reduction have yet to be determined. A Cochrane review examined twenty-one randomised controlled trials that included a total of 713 participants. This review found no evidence that low-GI diets influenced changes in certain well-known risk factors for CVD including HDL-cholesterol, LDL-cholesterol, TAG or total cholesterol concentrations. The authors of the Cochrane review reported that many of the trials included in the review were 'short-term, of poor quality and did not have sufficient power to detect clinical important differences'[41].

Observational studies and a very limited number of randomised controlled trials indicate a beneficial effect of bean consumption on short-term satiety and weight loss when combined with energy restriction[42,43], but these effects may not be related to the relationship between bean intake and glycaemic response. Few studies isolated and examined *P. vulgaris* species intake separately from other food groups[42,43], and none of these studies directly addressed the relationship between bean intake, glycaemic response and short-term satiety and weight loss, so results in this area should be interpreted with caution.

Although *P. vulgaris* species are known to decrease LDL-cholesterol, a well-known risk factor for CVD, in normocholesterolaemic and hypercholesterolaemic participants[35,36,44–47], this effect is most probably attributed to the soluble fibre found in the beans and not to the impact the beans have on glycaemic response. Nevertheless, other risk factors for CVD, such as oxidative stress, have been identified and low-GI foods such as beans and low-GI diets may favourably influence these risk factors.

In addition to chronic hyperglycaemia, elevated postprandial glucose can increase oxidative stress, worsen endothelium-dependent vasodilation and raise blood pressure[10,48–50]. Dysmetabolic changes after eating are significant contributors to CVD risk and individuals with T2DM are already at increased risk of CVD. On the other hand, controlling the postprandial glucose response by the inclusion of low-GI/GL foods in the diet can decrease CVD risk. Dietary patterns that include low-GI/GL foods, such as beans, were associated with a lower risk for CVD, even after accounting for other known risk factors such as cigarette smoking, obesity and family history in a prospective cohort study of 44 875 men aged 40–75 years[51].

Impact of Phaseolus vulgaris *species and glycaemic response on cancer and cancer risk factors*

Researchers hypothesise that glycaemic response may increase cancer risk through the modulation of hormone concentrations (for example, insulin-like growth factor) by insulin and that hyperinsulinaemia may increase cancer risk[52,53]. Studies examining the effect of GI and GL on the risk for various cancers (breast, colorectal, endometrial, gastric, ovarian, pancreatic, prostate, renal) report mixed results[54–81]. Most studies utilised either a cohort or case–control design, relying on FFQ to determine the average daily GI and GL of participants[54–59,61–64,67–70,74–81]. Inaccurate memory of foods consumed over the recall period (typically 1–2 years) and recall bias are potential confounding factors with FFQ and retrospective studies in general. Researchers also acknowledge that the reliability and validity of estimating average daily GI and GL from FFQ is questionable. Some GI and GL values have been obtained from small samples and the variability of the values is undetermined[54–58].

Few studies have reported the relationship of *P. vulgaris* species and glycaemic response on cancer risk (Table 3)[59,66,74]. We were unable to find any studies that had the examination of bean intake, glycaemic response and cancer risk or incidence as a primary objective. One cohort and one case–control study found weak associations between legume intake and a reduction in cancer risk related to a decrease in glycaemic response[59,74]. A randomised controlled trial found that a high-legume diet and a healthy American diet both favourably influenced biomarkers for cancer risk[66]. If the hypothesis that glycaemic response makes an impact on cancer risk via insulin actions and interactions, then incorporation of beans into the diet to modulate the glycaemic response could have a favourable impact on the risk for a variety of cancers. However, determining the impact of glycaemic response and beans on cancer risk in a human population will require more accurate and reliable methods of tracking diet intake over long periods of time.

Composition of *Phaseolus vulgaris* species of beans

According to the Dietary Guidelines for Americans and the United States Department of Agriculture, beans are classified as both a protein and a starchy vegetable source[82]. Beans contain a high amount of protein, with one serving of most bean types (half cup) providing 7–8 g. Beans are also an excellent source of fibre, providing 3–9 g of soluble and insoluble fibre per half-cup serving[83].

Beans contain very little fat, generally accounting for less than 3 % of the energy content, and have a very low saturated fat content[84]. Beans are also high in folate, Fe, Mg, Zn, *n*-3 fatty acids and antioxidants[7,85–88]. They contain phytate and phenolic compounds that may function similarly to glucose-lowering α-glucosidase or α-amylase inhibitor T2DM medications such as metformin and acarbose[7,86].

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Table 3. *Phaseolus vulgaris* species, glycaemic response and cancer risk

Study reference	Design	Sample size	Population	Duration	Treatment	Results	Conclusions
Cho *et al.* (2003)[59]	Cohort	714 cases of breast cancer from population of 90 655 over 8 years follow-up	Premenopausal women, aged 26–46 years	Cases identified between 1991 and 1999	None; semi-quantitative FFQ with 133 food items (initial) and 142 food items (follow-up) used to calculate GI and GL	GI and GL were not associated with breast cancer risk. There was a weak, non-significant inverse association between intake of fibre from legumes and breast cancer risk (RR for 5th quintile compared with 1st quintile = 0·79; 95 % CI 0·62, 1·02; *P* for trend = 0·04)	This study did not find a relationship between GI and GL and breast cancer risk Although there was a weak, non-significant inverse association between intake of fibre from legumes and breast cancer risk, there is no evidence that the relationship between legumes and glycaemic response is related to this association
Hartman *et al.* (2010)[66]	Randomised controlled trial	Sixty-four men	Men, aged 35–75 years, without a history of colorectal cancer	4 weeks on each diet	Control diet (high-GI (69) healthy American diet) High-legume (250 g/d), low-GI (38) diet	Both diets significantly reduced fasting CRP ($P=0·018$ legume and $P=0·007$ control) and sTNFRI ($P=0·005$ legume and $P=0·001$ control). The control diet significantly reduced sTNRFII ($P<0·001$) Neither diet decreased fasting insulin or C-peptide concentrations. The control diet reduced the fasting glucose concentration ($P=0·012$) and the legume diet increased it ($P=0·001$)	Both the control and high-legume diets had favourable effects on biomarkers associated with incidence of colorectal cancer and adenomas In this study, the legume diet increased fasting glucose concentrations, a result that is inconsistent with the typical reported influence of legumes on glycaemic response
Potischman *et al.* (1999)[74]	Case–control	568 cases; 1451 controls	Cases: Premenopausal women, aged 20–44 years, with breast cancer Controls: Premenopausal women, aged 20–44 years, without cancer	Cases identified between 1990 and 1992	None; modified version of standard 100-item NCI-Block FFQ	Increased intake of beans (OR 0·87; 95 % CI 0·7, 1·2; 4th quartile) and fibre from beans (OR 0·88; 95 % CI 0·7, 1·2 4th quartile) were associated with reduced breast cancer risk	Increased bean intake is associated with a minimal, if any, reduction in risk of early-stage breast cancer among young women. Although there was a small reduction in risk of early-stage breast cancer among young women associated with bean and bean fibre intake, there is no evidence that the relationship between beans and glycaemic response is related to this association

GI, glycaemic index; GL, glycaemic load; RR, relative risk; CRP, C-reactive protein; sTNFRI/II, soluble tumour necrosis factor-α receptors I and II; NCI, National Cancer Institute.

The predominant macronutrient in beans is carbohydrate, contributing 60–65 % of the energy content. Starch, the primary digestible carbohydrate in beans, can be categorised as readily digestible, slowly digestible and resistant starch[89]. All bean varieties including the *P. vulgaris* species contain a higher ratio of slowly digestible:readily digestible starch compared with other starchy foods. In general, most beans contain 30–40 % amylose, a linear polymer of glucose units (α1–4 linkages), whereas most other starches contain 20–30 % amylose. Starches with more than 30 % amylose are readily digestible or resistant starch depending on the amylose content and hydrothermal treatment applied to the food. Beans also contain a substantial amount of resistant starch, considered as a dietary fibre. Resistant starch is defined as any starch that resists digestion by amylase in the small intestine and progresses to the large intestine for fermentation by the gut bacteria[90,91]. Slowly digestible starch is associated with reduced glycaemic responses and lower postprandial glucose levels compared with readily digestible starch. This attenuated glycaemic response can benefit both insulin-resistant individuals and individuals with diabetes.

Proposed mechanisms of action

The mechanism of action responsible for the low glycaemic response to beans is multifaceted. Possible explanations include a high content of viscous fibre, protein, relatively high amylose starch and antinutrients. In addition, processing methods affecting the physical form of the beans may alter their glycaemic response.

Beans are commonly consumed in their whole form, or as a minimally processed food with little or no grinding. Eating the intact bean maintains the integrity of the cell wall, slowing digestion of the bean in the upper small intestine. Whole beans also have cell walls that are more resistant to digestion than the cell walls of cereal grains. Minimal or no processing of the bean combined with the resistance of the bean cell wall to digestion provides a likely primary mechanism of action that explains the low glycaemic response to beans[92].

Viscous fibres form a gel-like substance along the digestive tract, which may slow the rate of gastric emptying and absorption rate of nutrients. Inclusion of a viscous fibre with a test meal may reduce the blood glucose response by an average of 44 %[93]. Purified viscous fibres also reduce postprandial gastric inhibitory polypeptide and insulin levels more effectively than non-viscous fibres[94,95]. Beans are particularly high in soluble fibres that increase viscosity of the intestinal lumen or the unstirred water layer[96–98]. However, Tappy *et al.*[20] found significantly lower glucose and insulin responses to a bean meal alone compared with a potato meal with added bean fibre. Therefore, the attenuated glycaemic response seen as a result of bean consumption cannot be explained solely by the beans' fibre content.

The protein fraction of beans may interact with starch to reduce the digestibility and glycaemic response of that starch. Alli & Baker[99] found carbohydrates tightly bound to proteins isolated from uncooked beans using citric acid and sodium hydroxide extracts, providing evidence for a starch–protein interaction.

The ratio of amylose:amylopectin starch found in beans may also alter the glycaemic response. The higher molecular weight, greater surface area and branching structure of amylopectin make it subject to faster digestion than amylose. High-amylose meals (70 % amylose) compared with high-amylopectin meals (70 % amylopectin) result in significantly lower plasma glucose in healthy normoglycaemic adults at 30 and 60 min after meal consumption[100]. Among natural sources of carbohydrates, beans have the highest percentage of starch as amylose (30–40 %), which is 5–10 % more amylose than is found in most cereals[90].

In addition to protein–starch interactions and the nature of the starch in beans, the phytic acid content of beans may influence the glycaemic response after bean consumption. The phytic acid content of beans is high compared with non-bean foods. There is a negative correlation between phytic acid concentrations and glycaemic indices for non-diabetic adults (r −0·78, $P<0·001$)[101]. A study using unleavened bread made from navy bean flour (containing phytic acid) demonstrated that consuming the navy bean bread significantly reduced blood glucose area under the curve by 64 % compared with that of unleavened bread made from white wheat flour[102]. Removing the phytic acid from the navy bean flour significantly increased the glycaemic area under the curve by 141 %. Phytic acid is believed to inhibit starch digestion both directly and indirectly. Structurally, phytic acid binds directly with starch through phosphate bonds and reduces starch digestibility[102]. Indirectly, phytic acid may bind to cations such as Ca. Since the stability of α-amylases, including pancreatic α-amylase, is dependent on Ca[101], the lack of available Ca can decrease the effectiveness of α-amylases, slowing the rate of starch digestion. Phytic acid also binds to negatively charged groups on proteins, such as α-amylases, at neutral and alkaline pH[102], rendering them useless and reducing the digestion of starch by amylase.

Future directions

All beans are not created equal – nor do they elicit identical biological responses when consumed. Even though the GI values for beans are typically very low, studies examining the glycaemic effects of assorted beans from *P. vulgaris* species have demonstrated that the glycaemic response differs based on the bean used. Researchers should continue to study different beans from the *P. vulgaris* species to determine the individual glycaemic effects associated with each bean type.

Definitively determining if the form of the bean consumed changes the glycaemic response, or other positive biological effects associated with bean consumption, should be a priority. As interest in the *P. vulgaris* species increases, the food industry will probably formulate functional or manufactured foods that contain ground beans, bean powder, bean paste, etc. to address the marketing potential in this area. Research is needed to ensure that the various forms in which the bean can be utilised impart the same beneficial

properties associated with the consumption of whole beans, including maintaining the low-GI/GL qualities.

Studies such as the one conducted by Kallio *et al.*[103] demonstrate that foods can make an impact and act via molecular pathways by affecting signal transduction and gene function. The constituents of foods that act on these pathways go beyond the traditional macro- and micronutrient content typically reported for such foods. Research that identifies the phytochemical components of foods, including beans, is desperately needed to allow research in this area to progress. We are just beginning to explore the mechanisms of action that are responsible for the chronic disease risk-reduction benefits conferred by whole bean consumption. More research is required to define the pathways involved, including those related to changes in oxidative stress, endothelium-dependent vasodilation, and blood pressure, in order to determine the full extent of the influence that beans have on the prevention of chronic disease.

Summary

Traditional foods such as beans should be retained in the diet because of their many health benefits, including a positive impact on postprandial glycaemic response. Hyperglycaemia, whether it occurs following a meal or due to poorly controlled T2DM, is known to increase oxidative stress, contribute to hypertension and increase the risk for CVD. Examination of the glycaemic response to meals, especially culturally important food combinations such as beans and rice, is important for the prevention and control of hyperglycaemia-induced diseases.

Understanding the glycaemic responses elicited by the beans of the *P. vulgaris* market classification and how these responses vary depending on the bean consumed is essential. Since not all beans are equal in response, these findings will allow provision of accurate nutrition education to individuals who have, or are at risk for, T2DM.

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