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Review

The Role of Pulses in the Dietary Management of Diabetes

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ABSTRACT

Pulses are highly nutritious foods that are included as part of Canada's Food Guide to promote healthful eating, and they have established health benefits that can contribute to the dietary management of diabetes. A review of studies that have examined the effects of pulse consumption on health outcomes, integral to the management of diabetes, provides credible evidence for improvements in glycemic control, reduction of blood lipids and regulation of body weight. Results from acute feeding trials suggest that postprandial blood glucose response is significantly attenuated by a single pulse serving of between three-quarters and 1 cup. At lower doses, pulses attenuate postprandial blood glucose response more than similar amounts of starchy foods. Long-term pulse consumption of 5 cups per week appears to result consistently in improvements in glycemic control. There is high-quality evidence that supports a role for pulse consumption in the reduction of risk for cardiovascular disease; this provides a sound rationale for the regular incorporation of pulses at about two-thirds of a cup daily in the management of hyperlipidemia in persons with type 2 diabetes. Pulse consumption can contribute to improving satiety, reducing food intake and regulating body weight, which can reduce obesity risk and, in turn, improve diabetes management. Collectively, available evidence provides very good support for a role of regular pulse consumption in the prevention and management of diabetes.

RÉSUMÉ

Les légumineuses sont des aliments à haute valeur nutritive qui font partie du Guide alimentaire canadien visant à promouvoir la saine alimentation et ont des bienfaits établis sur la santé qui peuvent contribuer à la prise en charge nutritionnelle du diabète. Une revue d'études qui portaient sur les effets de la consommation de légumineuses sur les résultats cliniques, partie intégrante de la prise en charge du diabète, fournit des données probantes crédibles sur les améliorations de la régulation de la glycémie, la réduction des lipides dans le sang et la régulation du poids corporel. Les résultats provenant d'essais à court terme sur l'alimentation suggèrent que la réponse glycémique postprandiale est significativement atténuée par une seule portion de légumineuses de 3/4 à 1 tasse. À de plus petites portions, les légumineuses atténuent la réponse glycémique postprandiale plus que des quantités similaires de féculents. La consommation à long terme de 5 tasses de légumineuses par semaine semble invariablement entraîner des améliorations dans la régulation de la glycémie. Il existe des données probantes de qualité supérieure qui appuient le rôle de la consommation de légumineuses dans la réduction du risque de maladies cardiovasculaires. Ceci donne une raison valable à l'incorporation régulière d'environ 2/3 à 1 tasse de légumineuses par jour lors de la prise en charge de l'hyperlipidémie chez les personnes atteintes du diabète de type 2. La consommation de légumineuses peut contribuer à l'augmentation de la satiété, la réduction de l'apport alimentaire et la régulation du poids corporel, lesquelles peuvent réduire le risque d'obésité et, en contrepartie, améliorer la prise en charge du diabète. Collectivement, les données probantes disponibles apportent un très bon soutien au rôle de la consommation régulière de légumineuses dans la prévention et la prise en charge du diabète.

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Introduction

A major goal in the management of persons with diabetes is the achievement of optimal glycemic control because chronic elevation of blood glucose is linked to organ and nerve damage and to increased risk for cardiovascular disease (CVD) (1). In 2015, it was estimated that about one-third of Canadians were affected by either diabetes or prediabetes, and this figure is expected to increase significantly in the next decade. Current estimates suggest that the Canadian healthcare system is burdened with an annual expenditure of about $3 billion for the management of diabetes and its related complications. Globally, the prevalence of diabetes is increasing, and there is good evidence to suggest that this is due largely to excessive weight gain and obesity, resulting from poor diets and lack of physical activity (2). As such, it is imperative that more emphasis be placed on dietary and lifestyle interventions to complement standard clinical management in order to achieve optimal glycemic control.

In the dietary management of diabetes, quantity as well as quality of fat and carbohydrate intake must be carefully considered because they may not always confer desirable health benefits (2). In particular, the consumption of high-fibre, low glycemic index (GI) carbohydrates has been shown to be associated with decreased risk for developing type 2 diabetes (2). One such source of carbohydrates is pulses, defined as dry, edible leguminous crops that include beans, chickpeas, peas and lentils (3). Pulses are rich in carbohydrates (50% to 65%), fibre (4% to 7%), protein (5% to 10%) and several micronutrients (3). They also contain natural enzyme inhibitors that could slow the breakdown of carbohydrates and lipids in the small intestines, partially explaining their low GI values. Given the agricultural, economical and nutritional importance of pulses and their production in an environmentally sustainable manner, the Food and Agriculture Organization of the United Nations has declared 2016 the International Year of Pulses.

The majority of the world's pulses are produced in North America, with Canada being the world's largest exporter of lentils and peas (3). However, human consumption in North America is relatively low; on average, only about 13% of Canadians consume pulses daily, with high pulse consumers, mainly of Asian heritage, also having higher intakes of carbohydrate, fibre, protein and several micronutrients. Health Canada has included pulses in the Canadian Food Guide as part of a well-balanced diet, with the recommendation that beans and lentils, as meat alternatives, provide useful approaches to reduce dietary intake of saturated fats. Both the Canadian Diabetes Association and the American Diabetes Association also recommend consumption of pulses as part of diet therapy in their clinical practice guidelines (1,3) but provide no guidance with respect to number of servings, serving size or frequency of intake.

This review summarizes recent observational studies that have examined dietary pulse intakes and risk for type 2 diabetes along with human clinical trials (acute and long-term) that have investigated the effectiveness of pulses in attenuating postprandial blood glucose responses (PBGRs) and overall glycemic control (Table 1). This review also provides estimates of the quantity of pulses used in the various studies and offers guidance about the minimum effective dose required for improved health outcomes, including reduction of blood lipids, satiety and body weight management, in persons with type 2 diabetes.

Epidemiologic studies

Several observational studies have examined the association between low-GI or high-fibre diets containing pulse, or pulse-rich diets, with the occurrence of type 2 diabetes. Inevitably, a major focus has been on the Mediterranean diet, which is rich in pulses, whole-grain cereals, fruits and vegetables and low in meats and highly processed foods. First introduced in the 1970s by Ancel Keys during the Seven Countries Study (4,5), the Mediterranean diet has been associated with a lower risk for developing several chronic diseases, including type 2 diabetes, CVD and obesity (4,6). A recent meta-analysis of 10 prospective studies, including 136,846 participants from Europe and the United States, found that the Mediterranean diet was associated with a 23% reduced risk for type 2 diabetes (4). Similarly, a meta-analysis of 50 studies, including 534,906 participants from Europe, Australia, Israel and the United States, reported that consumption of the Mediterranean diet correlated with lower fasting blood glucose (FBG) levels and reduced risk for metabolic syndrome (6). Using dietary data from the Greek European Prospective Investigation into Cancer and Nutrition (EPIC) cohort of 23,349 persons committed to a traditional Mediterranean diet, associated median pulse consumption was estimated at 9.13 (95% CI, 5.75 to 13.32) grams per day among men and 6.66 (95% CI, 3.62 to 10.52) grams per day among women (5). Further, pulse consumption was 1 of the strongest predictors of diabetes risk, exerting a protective effect (7), with high consumption contributing 10% to 11% to the association of adherence to the Mediterranean diet score and lower mortality (5). A meta-analysis of 5 observational studies estimated that 4 weekly servings of 100 grams (~1/2 cup) of cooked pulses correlated with a 14% reduction in risk for ischemic heart disease, which is higher in persons with type 2 diabetes (8).

Pulses have been highlighted in many studies that examined the relationship between low dietary GI and glycemic load (GL) and risk for type 2 diabetes; however, the conclusions have not always been consistent. For example, a meta-analysis (9) of 10 studies of GI and type 2 diabetes and 14 studies of GL and type 2 diabetes, conducted in the United States, Europe, China and Japan, showed that persons with the highest dietary GI and GL had significantly higher relative risk for type 2 diabetes. In contrast, a cohort study in 8 European countries found no relationship between GI, GL and type 2 diabetes. It is likely that differences in study design, study population, dietary assessment tools and source of dietary fibre could account for these contrasting results (9). In China, a 15-year study of dietary patterns of 4096 adults reported that increased intake of pulses was associated with significantly lower levels of glycated hemoglobin (A1C) and lower incidence of type 2 diabetes (10). Similarly, the Tehran Lipid and Glucose Study, in which participants were followed for 20 years, concluded that increased intake of total dietary fibre, soluble and insoluble fibres, were inversely associated with metabolic syndrome (11). Importantly, of the forms of dietary fibre that contributed to this association, cereal and pulse fibres produced the strongest effects, whereas vegetable and nut fibres were unrelated (11).

Observations from several epidemiologic studies and meta-analyses have provided useful insights into the association between pulse consumption and risk for type 2 diabetes and, collectively, they have informed the design and execution of acute and long-term human clinical studies to better define the relationship between pulse consumption and improved glycemic control.

Acute studies of pulse consumption and glycemic response

Pulses have been found to attenuate PBGR, also referred to as the incremental area under the blood glucose response curve (AUC), relative to similar amounts of starchy foods in healthy persons as well as in those with type 2 diabetes. Not only is this inherent property of pulses highly desirable in the management of diabetes, it may also be useful in delaying the onset of overt diabetes in persons with impaired glucose tolerance. The short-term effect of pulses on postprandial glycemia in individuals with diabetes was recently reviewed by Augustin et al in a meta-analysis of 32 acute clinical studies conducted from 1983 to 2003 (12). Trials were examined

Table 1
Impact of pulse consumption on control of glycemia

Study	Design	Sample size and population	Duration	Treatment	Dose; format	Results	Conclusions
Epidemiologic studies							
Trichopoulou et al (2009) (5)	Cohort	23,349 healthy men and women	Mean of 8.5 years	Low, medium and high adherence to an MD	–	High legume consumption accounted for 9.7% of the inverse association of all-cause mortality and high adherence to an MD	Legumes are an important component of an MD because they contribute to the health benefits of the diet
Hosseinpour-Niazi et al (2011) (11)	Cross-section	2457 Iranian men and women	–	–	–	An inverse association between MS and total dietary fibre, soluble and insoluble fibre, as well as types of total dietary fibre (fruit, cereal and legume fibre); no correlation with vegetable and nut fibre	Increased intake of legume fibre is associated with lower prevalence of MS
Batis et al (2014) (10)	Cohort	4096 Chinese men and women	15 years	–	–	Participants scored on dietary trajectories and those who started with a healthier score and higher legume consumption had 1.64% lower A1C levels; nonsignificant 6.47% lower HOMA-IR and lower odds of diabetes	A healthy diet that includes legumes significantly lowers A1C levels
Acute studies of pulse consumption and glycemic response							
Nestel et al (2004) (14)	Randomized crossover trial	19 mildly overweight middle-aged men and women	3 test meals consumed at least 1 week apart	Chickpeas White bread (C) Wheat-based foods (C)	50 g avCHO/200 g pulse; Gently mashed	BG and insulin were lower after chickpeas at 30 and 60 min vs. WB and wheat foods (p<0.05); HOMA-IR was lower after 2 hours for chickpeas vs. WB and wheat foods (p<0.05)	Chickpeas can lower postprandial glycemic and insulinemic responses compared to WB and wheat foods
Johnson et al (2004) (22)	Randomized crossover trial	11 healthy men and women	4 test meals consumed at least 1 week apart	24.3% CHB 24.3% chickpea EXB WB (C)	50 g avCHO; Powdered	At 90 min BG was lower for CHB vs. WB (p=0.005); at 120 min BG was lower for EXB vs. WB (p<0.001); glucose AUC was not significantly lower for CHB vs. WB (p=0.087); insulin AUC and insulin index were higher for CHB vs. WB (p<0.05)	CHB decreases peak BG at 90 mins but increases insulin response
Mollard et al (2012) (15)	Randomized crossover trial	24 healthy men and women	5 test meals consumed 1 week apart	Pasta, sauce and pulse (chickpeas, lentils, navy/ haricot beans, yellow peas) Pasta and sauce alone (C)	44% energy density from whole pulse	After 260 min PBGR for chickpeas, lentils, beans were ~35% lower than pasta and sauce alone (p<0.0001)	Pulses consumed in a pasta meal significantly lowers PBGR compared to control
Smith et al (2012) (24)	Randomized controlled trial	20 healthy men, aged 20–30 years	5 test meals consumed 1 week apart	Tomato soup+YPF Tomato soup+YPP Tomato soup alone (C)	YPF: 10 g; 20 g YPP: 10 g; 20 g; Powdered	YPP at 10 g and 20 g lowered mean BG between 0–30 min (p<0.05), but not YPF at 10 g and 20 g (p>0.05) vs. C; YPP and YPF did not lower mean BG after 120 min	Protein may be responsible for short-term effects of yellow peas in regulation of glycemia
Nilsson et al (2013) (18)	Randomized crossover trial	16 healthy men and women	9 PM test meal followed by an 8 AM standardized breakfast; conducted twice, 1 week apart	9 PM: Brown beans or WB (C) 8 AM: WB	35 g avCHO; Whole pulse	Beans at dinner followed by WB at breakfast significantly (p<0.05) lowered glucose (23%) and insulin (16%) response vs. WB dinner treatment	An evening meal of beans can produce a lower PBGR and insulin response to WB eaten at breakfast
Mollard et al (2014) (25)	Randomized crossover trial	15 healthy men	5 meals consumed 1 week apart	YPF YPP Combination of YPF and YPP (each consumed with noodles and tomato sauce) WYP; consumed with tomato sauce) Noodles and tomato sauce alone (C)	YPF: 7 g; YPP:10 g; Combination: 7 g YPF+10 g YPP; Powdered WYP: 406 g; Whole pulse	Relative glucose AUC (0–215 min) were: Combination <WYP <YPP <Control <YPF (p=0.003) with significant differences between the combination and control; and between WYP and control	WYP and a combination of YPF and YPP significantly lowered PBGR
Anderson et al (2014) (20)	Randomized crossover trial	Exp 1: 17 healthy young men; Exp2: 12 healthy young men; Exp3: 12 healthy young men	Exp 1,2,3: 4 test meals consumed 1 week apart	Exp 1: Navy bean Exp 2: Lentil Exp 3: Chickpea Whole wheat flour (C) (served with tomato sauce)	25 g avCHO; Exp 1,2,3: Whole, pureed, powdered	Navy beans and lentils, but not chickpea flour significantly (p<0.05) lowered PBGR vs. whole wheat flour; whole lentils also lowered PBGR (p<0.05)	Pureed and powdered pulses retain the ability to lower postprandial BG to the same degree as whole pulse, despite the effect of processing

(*continued on next page*)

Table 1 (*continued*)

Study	Design	Sample size and population	Duration	Treatment	Dose; format	Results	Conclusions
Zafar et al (2015) (23)	Randomized crossover trial	13 healthy young females, 17–25 years	4 meals consumed 6–12 days apart	25% Chickpea-WWB (25% ChB) 35% Chickpea-WWB (35% ChB) Whole wheat bread (WWB; C) WB (C)	50 g bread; Powdered	ChB at 35% and 25% significantly lowered AUC (0–90 min) vs. WB by 48% and 25%, respectively; compared to WWB only 35% ChB significantly lowered AUC (0–90 min) by 38%	Addition of 35% chickpea flour to whole wheat bread significantly reduces blood glucose response vs. WB or WWB
Augustin et al (2016) (26)	Randomized crossover trial	10 healthy men and women	11 meals consumed over 15 weeks	Hummus (processed chickpeas) WB (C) Hummus+white bread	Hummus (28 g, 112 g, 256 g) WB alone: 25 g avCHO Hummus (28 g, 112 g, 256 g)+WB (50 g avCHO)	GI and insulin index of hummus significantly lower vs. WB (p<0.05); glucose and insulin AUC for hummus alone were significantly lower vs. WB, except for insulin AUC of hummus served at 25 g avCHO; peak rise in BG and insulin were significantly lower after hummus vs. WB	Hummus has retained the ability of chickpeas to lower PBGR without a disproportionate insulin response
Long-term pulse consumption and glycemic control							
Barnard et al (2006) (29)	Randomized controlled trial	99 men and women with type 2 diabetes	22 weeks	Low-fat vegan diet encouraged to increase pulse vs. 2003 ADA guidelines diet (C)	Unrestricted	A1C levels were lowered in all participants (p<0.05), with the vegan group experiencing a larger decrease; FBG was lowered in all participants, with no significant effect of diet	A diet based on the 2003 ADA guidelines and a vegan diet containing pulse can both lower A1C and FBG levels, but the vegan-pulse diet results in a larger decrease in A1C levels
Marinangeli & Jones (2011) (33)	Randomized crossover trial	23 overweight, hyperchol-esterolemic men and women	12 weeks	Muffins containing WPF, FPF hull fibre); or white wheat flour (WF; C)	50g/day (~0.5 cup); Powdered	FBI decreased on WPF by 13.5% and on FPF by 9.8% vs. WF (p=0.01); HOMA-IR decreased by 25% for both WPF and FPF vs. WF (p<0.05) FBG was not significantly lowered	WPF and FPF can be incorporated into foods to effect a decrease in FBI and HOMA-IR
Jenkins et al (2012) (28)	Randomized controlled trial	121 men and women with type 2 diabetes	3 months	Low-GI pulse rich (beans, chickpeas, lentils) diet or high wheat-fibre diet	1 cup/day: Cooked whole	Relative reduction in A1C levels after the low-GI pulse diet was greater vs. high wheat-fibre diet by −0.2% (p<0.001); CHD risk reduction (−0.8%; p=0.003) was higher on the low-GI pulse diet (p=0.003) due to a greater relative reduction in systolic blood pressure on the low-GI-pulse diet vs. high wheat-fibre diet (p<0.001)	Adding pulses to a low-GI diet improves glycemic control and reduces CHD risk in persons with type 2 diabetes
Mollard et al (2012) (32)	Randomized controlled trial	40 obese or overweight men and women	8 weeks	Pulse-rich (lentils, navy beans; chickpeas, yellow peas) diet; or energy-restricted diet (C)	5 cups/week	A1C, AUC and HOMA-IR decreased in both groups (p<0.05); insulin AUC decreased on the energy-restricted diet and by 13.9% in females on the pulse-rich diet, but increased by 27.3% in males on the pulse-rich diet (p<0.05)	Both a pulse-rich diet and an energy-restricted diet can lower A1C, BG, AUC and HOMA-IR; insulin AUC is lowered by an energy restricted diet and in females on a pulse-rich diet
Hosseinpour-Niazi et al (2015) (30)	Randomized crossover trial	31 men and women with type 2 diabetes	20 weeks	Therapeutic diet with 2 servings of red meat replaced with cooked lentils, chickpeas, peas and beans 3 days per week Standardized therapeutic diet with red meat (C)	1 cup on 3 days/week	FBG and FBI decreased in the legume-rich diet vs. the legume-free diet (p=0.04 and p=0.04, respectively)	Therapeutic lifestyle diet with added pulses lowers FBG and FBI compared to a legume-free diet in individuals with type 2 diabetes
Saraf-Bank et al (2016) (31)	Randomized crossover trial	26 men and women, first-degree relatives of patients with diabetes	14 weeks	Pulse-rich diet (lentils and pinto beans); or habitual diet containing a similar nutrient profile (C)	4 servings of pulse/week (65 g or ~1 cup/serving)	FBG not significantly affected on either pulse diet (p=0.73) or habitual diet (p=0.14); A1C not different on either pulse (p=0.37) or habitual diet (p=0.07)	A pulse-rich diet is associated with nonsignificant increases in FBG and A1C in healthy individuals

ADA, American Diabetes Association; *A1C*, glycated hemoglobin; *AUC*, area under the blood glucose response curve; *avCHO*, available carbohydrate; *BG*, blood glucose; *C*, control treatment; *CHB*, chickpea bread; *CHD*, coronary heart disease; *EXB*, extruded flour bread; *FBG*, fasting blood glucose; *FBI*, fasting blood insulin; *FPF*, fractionated pea flour (hull fibre); *GI*, glycemic index; *HOMA-IR*, homeostatic model assessment of insulin resistance; *MD*, Mediterranean diet; *MS*, metabolic syndrome; *PBGR*, postprandial blood glucose response; *WB*, white bread; WF, white wheat flour; *WPF*, whole-pea flour; *WWB*, whole-wheat bread; *WYP*, canned yellow peas; *YPF*, yellow pea hull fibre; *YPP*, yellow pea protein.

according to the form of pulse used in the various studies and included chickpeas, beans, lentils and split peas. Most of these acute feeding trials tested the effect of 50 grams (~2 cups cooked) of available or glycemic carbohydrate on PBGR in persons with diabetes. Overall, the pooled analyses indicated that pulse consumption resulted in a 50% lower PBGR compared to a white-bread control containing the same amount of available or glycemic carbohydrate. Chickpeas were found to lower PBGR by a greater amount than beans and lentils, which had similar intermediate effects (12).

Several additional studies, which focused on the consumption of the *Phaseolus vulgaris* species of beans, such as navy beans, pinto beans, red kidney beans and black beans, have found similar effects of attenuating the acute glycemic responses in participants (13). In particular, 1 study reported an overall 45% reduction in PBGR through consumption of boiled beans compared with 24 other starchy foods, such as vegetables, biscuits, breakfast cereals, breads and pastas, in 25 participants without diabetes (13). Nestel et al (14) examined the PBGR of single meals of chickpeas, wheat-based foods or white bread, standardized for available or glycemic carbohydrate, in healthy middle-aged participants. Compared to the other meals, chickpeas produced significantly lower blood glucose at 30 and 60 minutes and significantly higher insulin sensitivity at 2 hours (14).

Pulses are usually consumed in combination with items from other food groups, so it is important to reconcile the effect of whole pulses in the context of mixed meals. To examine this, Mollard et al (15) fed healthy volunteers combined mixed meals of different types of pulses (at 44% energy density) along with a control macaroni pasta and tomato sauce meal and found that all pulses produced lower peak blood glucose responses compared to the control. Chickpeas, lentils and navy beans produced significantly lower (~35%) PBGRs than pasta (15). Similar results have been obtained in persons with type 2 diabetes who consumed meals of either white rice alone or mixed meals of rice and either pinto, black or red kidney beans that were standardized for available or glycemic carbohydrate (13). All 3 mixed meals of rice and beans produced lower PBGRs than the white rice control; however, the effects of pinto beans and black beans were significant, but not those of kidney beans. For practical purposes, the serving sizes of the various pulses and the estimated volumes (16) used to achieve these effects were: 128 grams (~1.1 cup) white rice with either 305 grams (~1.7 cup) pinto beans; 243 grams (~1.3 cup) black beans; or 267 grams (1.3 cup) red kidney beans vs. 180 grams (~1.1 cup) rice alone (13).

The acute blood glucose-attenuation effect of pulse consumption has been shown to extend to the subsequent meal and even to the following day. Although few studies exist, it has been suggested that this residual, or second-meal, effect results from improved glucose disposal through mechanisms not fully understood (17). Studies included in a 2012 review concluded that breakfast carbohydrate tolerance was improved when lentils had been consumed as part of a meal eaten the previous evening (17). Further, lentils eaten at breakfast were also shown to result in lower PBGRs and peak blood glucose levels after subsequent meals eaten at lunchtime (17). More recently, Nilsson et al (18) had healthy volunteers consume dinners comprising equal amounts of available or glycemic carbohydrate, such as brown beans or white bread, followed the next morning by a standardized breakfast of 50 grams of available or glycemic carbohydrate white bread. Beans, in contrast to white bread eaten on the previous evening, were associated with a 23% decrease in PBGRs and a 16% decrease in insulin responses at breakfast (18). The second-meal effect is a phenomenon that requires further work because it has the potential to impact the dosing of medications in persons with diabetes.

Pulse flours are being incorporated into food products with increasing frequency by the food industry in an attempt to meet consumer demands for more healthful foods and to increase the consumption of pulses. One concern that arises is whether the biologic benefits observed with whole pulses are retained after they are processed into flour. For example, blood glucose responses following consumption of boiled lentils or boiled lentils blended into a paste were flattened when compared to white bread but were significantly increased when boiled and blended lentils were dried at 250°F and milled into a flour (19). More recently, Anderson et al (20) assessed the acute effects of powdered, pureed and whole canned pulses on PBGRs using navy beans, green lentils and chickpeas standardized at 25 grams of available or glycemic carbohydrate (~1 cup) and served with tomato sauce. The study found similar low PBGRs for all pulses and concluded that processing pulses into flour does not result in the loss of their PBGR-lowering property and, therefore, encouraged the continued use of pulse powders as value-added food ingredients to lower PBGRs. The processing methods used in these 2 studies differed, but they suggest that further work is needed to determine the optimal processing method to be used for pulse-based flours. It appears that the production of pulse flour through cooking, then heat drying and milling results in the loss of the PBGR-lowering property, whereas dry roasting (e.g. micronization, as used by Anderson et al [20]), followed by milling does not.

Dahl et al (21) conducted a review of 2 acute clinical trials involving *Pisum sativum L.* peas and found that both yellow pea flour and pea starch lowered glycemic responses compared to maize starch when incorporated into a 30 gram carbohydrate soup, with pure pea starch producing a 47% lower glycemic and a 54% lower insulin response. Further, when whole yellow pea flour was incorporated into biscotti, the glycemic response was significantly lower than that found with whole-wheat biscotti, but this was not the case with banana bread or pasta (21). Similarly, Johnson et al (22) prepared breads by substituting 24% of the wheat flour with flours from chickpeas and extruded chickpeas and found no significant differences in PBGRs between these breads and a white bread control served at breakfast. This study probably lacked sufficient power to detect the expected change in PBGRs and was likely confounded by the feeding protocol that served the test and control foods with 6 grams of margarine and 20 grams of jam. As a follow-up, Zafar et al (23) investigated the PBGR-lowering effects of chickpea-wheat composite breads that incorporated 25% and 35% chickpea flour into whole-wheat flour breads. When a standard weight (50 g) of these breads was tested in healthy volunteers with 5 grams of butter and water, PBGRs were significantly lower (by 48%) for the 35% chickpea composite bread compared to the white bread; 25% chickpea bread was 25% lower than the white bread control, suggesting that the effect may not be linear (23). This desirable effect on blood glucose might have resulted from the replacement of available carbohydrates from wheat flour with soluble fibres and complex carbohydrates from chickpea flour, resulting in increased intestinal viscosity and reduced glucose absorption.

In addition to flour, pulse fractions may also be capable of lowering PBGRs. In an acute study, Smith et al (24) found that yellow pea protein eaten by healthy men at 10 grams and 20 grams in a tomato soup led to significantly lower blood glucose levels 30 minutes after consumption, compared to the control of soup alone. The authors argued that the protein, and not the fibre fraction of whole yellow peas, is responsible for the lowering of blood glucose levels up to 30 minutes after consumption. Using a similar repeated-measures crossover trial design, Mollard et al (25) assessed PBGRs in healthy men fed pea hull fibre, pea protein, a combination of pea protein and hull fibre, and canned yellow peas and compared these levels to those of a control of noodles and tomato sauce. The study showed that yellow peas and the combination of pea protein and fibre produced significantly lower PBGRs compared to the control (69% and 66% of the control value, respectively). Pea protein alone also produced lower glucose AUCs, but they were not significant. Hence, pea protein and the combination of pea protein and fibre could be considered valuable food ingredients for improving glycemic control (25).

An alternative approach to increasing the versatility of chickpeas is by processing them into hummus, which can be used as a spread. Augustin et al (26) demonstrated that despite processing, hummus retains the beneficial effects of pulses on blood glucose levels. Varying doses of hummus were served to healthy volunteers and compared with appropriate white bread portions; the results showed that PBGRs after eating hummus were 4 times lower than those of white bread and did not compromise insulin levels.

Long-term pulse consumption and glycemic control

The availability of high-quality long-term human feeding trials has been identified as a significant knowledge gap in substantiating a health claim for pulses. In an attempt to assess the long-term effects of pulses on glycemic control in individuals with and without type 2 diabetes, Sievenpiper et al (27) recently performed a meta-analysis that included 41 randomized control trials, carried out from 1981 to 2007. The trials were mostly crossover in design and were grouped into 3 categories: pulses alone, pulses as components of a low-GI diet and pulses as components of a high-fibre diet. In the pulses-only studies, participants received an average daily dose of 152.1 grams (~0.8 cup) of various beans, including chickpeas, black-eyed peas, red beans, white kidney beans and black beans. The mean follow-up period was 6.7 weeks, The results showed that both FBG and fasting blood insulin (FBI) levels were significantly reduced. In this meta-analysis, 2 studies achieved very strong intervention effects and may have introduced bias; however, the analysis clearly showed that chickpeas served alone had the strongest FBG-lowering effects, and benefits were observed in doses less than 100 grams (~0.6 cup) per day (27).

Analysis of 19 trials that incorporated pulses in an attempt to lower diet GI, and with an average follow-up period of 14.3 weeks, found that A1C levels were lower in people with diabetes (27). Among 11 trials that examined pulses as components of high-fibre diets, with a mean fibre content of 56 grams per day and average follow-up periods of 19.9 weeks, FBG and FBI were significantly reduced. The analysis showed that when pulses are major contributors to dietary fibre intake, the minimum fibre intake required to reduce FBG was 40 grams per day. In 2 studies that provided information on the dose, 200 grams per day (~1 cup/day) of pulses as part of a high-fibre diet resulted in significantly decreased FBG and A1C levels (27). Similarly, in a randomized controlled trial, Jenkins et al (28) sought to compare the long-term effects of a low-GI, legume-rich diet with that of a high-insoluble fibre diet, achieved through consumption of whole-wheat products by persons with type 2 diabetes, with the primary outcome looked for being lower A1C levels. The low-GI diet included a daily serving of 1 cup (~190 g/day) of cooked beans, chickpeas and lentils, which was eaten for 3 months. Although A1C levels decreased significantly in both study groups, the relative reduction in the low-GI legume diet was significantly greater than that in the high wheat-fibre diet by −0.2% (95% CI, −0.3% to −0.1%). When the Framingham cardiovascular disease predictive equation was used to assess risk for coronary heart disease as a secondary outcome, the pulse-rich diet was found to lower this risk factor substantially compared to the high wheat-fibre diet, primarily due to a significant lowering of systolic blood pressure in those on the low-GI legume diet (28). Collectively, the consumption of pulses by themselves, as part of a low-GI diet or as part of a high-fibre diet, can significantly improve medium- to long-term glycemic control, as indicated by improvements in the FBG, FBI and glycated protein levels of the participants.

The effect of pulse-based diets on glycemic control has been compared with that of both plant- and meat-based diets. For example, Barnard et al (29) compared the effect of an intervention diet based on the 2003 ADA guidelines with that of a low-fat vegan diet that included guidance for increasing consumption of legumes with unrestricted portion sizes in persons with type 2 diabetes. After 22 weeks, participants in both treatments experienced a decrease in FBG and A1C levels, but those on the vegan diet had significantly lower A1C levels than those on the ADA diet (29). Similarly, in a recent randomized crossover trial, substituting red meat with 1 cup of pulse on 3 days per week for 8 weeks by persons with type 2 diabetes resulted in significant improvements in FBG and FBI levels (30).

Studies of the long-term effects of a pulse-rich diet in persons with type 2 diabetes consistently show improvements in markers of glycemic control (i.e. FBG, FBI, A1C levels). In contrast, conflicting results have been obtained in several studies involving people who are obese and at risk for developing type 2 diabetes (31,32). In 1 such study, first-degree relatives of people with diabetes were randomized to habitual diets or diets rich in lentils or pinto beans (4 servings per week) for 6 weeks, with a 2-week washout period; the results showed nonsignificant changes in FBG and A1C levels (31). This result might have been due to the relatively high fibre content and the similarity in nutrient composition of the 2 diets. In another study (32), overweight and obese adults were randomized to an energy-restricted diet or a pulse-rich diet consisting of 5 cups of pulses per week for 8 weeks. The pulse-rich diet resulted in modest but nonsignificant decreases in PBGRs and A1C levels compared to the energy-restricted diet. Marinangeli and Jones (33) obtained mixed results when they compared the effects of long-term consumption of fractionated yellow pea flour and whole yellow pea flours with a white flour control on insulin resistance in 23 overweight adults. Pulse dose was one-half cup per day, and flours were baked into muffins, which participants consumed, 1 per day, for 28 days, followed by a 28-day washout period. Whole yellow pea flour and fractionated yellow pea flour significantly lowered the homeostatic model assessment of insulin resistance but not FBG levels, compared to white flour.

Pulse consumption and blood lipids

Improvements in blood cholesterol levels with pulse consumption have been examined in many studies, and they are relevant to diabetes management because hyperlipidemia increases the risk for CVD, 1 of the major complications of diabetes (1). In an early meta-analysis, Anderson et al (34) examined the effects of pulses on circulating lipids as found in 11 randomized controlled trials published between 1983 and 2000. The studies examined a median pulse dose of two-thirds of a cup for durations of 2 to 16 weeks. Results showed significant reductions in serum total cholesterol by 7.2% (95% CI: 5.8, 8.6); low-density lipoprotein (LDL)-cholesterol by 6.2% (95% CI: 2.8, 9.5); and triglycerides by 16.6% (95% CI: 11.8, 21.5), with no significant change in high-density lipoprotein (HDL)-cholesterol. Later, Bazzano et al (35) combined 10 randomized controlled trials published between 1989 and 2007, with a minimal duration of 3 weeks, a median pulse dose of two-thirds of a cup and a focus on non-soy legumes. These results also showed significant reductions in total cholesterol by 0.31 mmol/L (95% CI: 0.42, 0.19); LDL-cholesterol by 0.21 mmol/L (95% CI: 0.30, 0.12), and no significant changes in triglyceride or HDL-cholesterol levels. Most recently, Ha et al (36) published the most comprehensive systematic review and meta-analysis of 26 randomized controlled trials published between 1990 and 2012 to further examine the effects of pulse consumption, this time on selected therapeutic lipid targets for CVD risk reduction, including LDL-cholesterol, non-HDL cholesterol and apolipoprotein B. The included studies, which used a median pulse dose of 130 grams per day (~2/3 cup) and durations of 3 weeks to 1 year, revealed that, again, LDL-cholesterol was significantly reduced, this time by 0.17 mmol/L (95% CI: 0.25, 0.09). Non-HDL-cholesterol was also reduced, but not quite significantly, by 0.09 mmol/L (95% CI: 0.19, 0.00) and apolipoprotein B was not significantly affected, although it was included in only 1 study as an outcome measure.

These meta-analyses document the intensity of research activity in the effects of pulses on blood lipids. More important, their results reveal consistently significant reductions in blood cholesterol of magnitudes comparable to those of currently approved therapeutic health claims. This high-quality evidence strongly supports a role for pulse consumption in the reduction of risk for CVD and provides good rationale for the regular incorporation of pulses at approximately two-thirds of a cup daily in the management of hyperlipidemia in persons with type 2 diabetes.

Pulses and satiety, food intake and body-weight management

Given the relevance of obesity prevention to diabetes management (37), it is worth considering the growing number of studies that have examined the effects of pulse consumption on measures of satiety, food intake and body weight. The low energy density of pulses, along with their composition of complex carbohydrates, resistant starches and proteins, establish biologic plausibility for positive effects on body-weight management. Previous reviews of this topic by McCrory et al (38) and Marinangeli and Jones (39) along with Health Canada's consideration of a satiety health claim for foods (40) have prompted ongoing research in this area.

To determine how different forms of pulses relate to satiety, a complex study by Wong et al (41) examined whether the acute effects of pulses on satiety and food intake depended on processing, their inclusion in recipes or their variety. Experiment 1 tested processing (2 types of canned navy baked beans vs. homemade baked beans from dried beans); experiment 2 tested recipes (3 bean recipes) and experiment 3 tested variety (chickpeas, lentils, navy beans and yellow peas). All experiments were conducted in healthy men, and all collected measures of subjective appetite before and 120 minutes after consumption of each treatment, followed by measurement of food intake from a meal of pizza. Results showed significant reductions in appetite with the homemade, but not canned, navy beans and showed lower food intake with the canned but not the homemade navy beans (experiment 1); showed no significant changes in appetite or food intake for any of the bean recipes (experiment 2); and showed reductions in appetite but not in food intake for all pulse varieties, with no differences among them (experiment 3). Collectively, these results suggest an important role for pulses in reducing appetite and food intake when they do not depend on processing, recipes or variety (41).

Another study sought to identify the component of pulses responsible for effects on satiety and food intake by comparing the isolated protein and fibre fractions of yellow peas consumed in a tomato soup by healthy males (24). The yellow pea protein, but not the fibre, significantly reduced food intake at pizza meals served at 30 but not at 120 minutes, with no significant effects on appetite, suggesting that any benefits of yellow peas beyond 30 minutes cannot be explained only by their protein component. A follow-up study by the same research group (25) did not observe significant effects on appetite or food intake at 135-minutes after a pizza meal with treatments of yellow pea protein and fibre components alone or in combination when consumed within a macaroni and tomato sauce. Because pulses are commonly consumed as part of a high-carbohydrate meal, Mollard et al (15) examined appetite and food intake in healthy men who consumed meals of pasta and tomato sauce with 44% of energy from different pulse types followed by a pizza meal 4 hours later. Appetite and food intake were significantly reduced at both the pulse and pizza meals; however, the effects varied by pulse type.

Acute effects of pulses on satiety and food intake were studied most recently in a systematic review and meta-analysis combining 9 studies (42). The summarized results showed that pulse consumption significantly increased satiety by 31%; however, there was no significant effect on food intake at a second meal. Although study heterogeneity may have precluded a significant effect, it could be that chronic exposure to pulses is needed to reduce food intake.

Chronic exposure to pulses was examined in an 8-week study by Mollard et al (32) that found reduced energy intake in overweight and obese adults who consumed 5 cups of mixed pulses in various dishes each week. Another chronic study that focused on consumption of chickpeas (104 g/day, or approximately just over ~½ cup/day) for 12 weeks reported significantly increased satiety and reduced intake of cereal foods (43). In comparison, an earlier, acute chickpea study did not find significant changes in satiety or food intake (22).

Whether the potential of pulses to increase satiety and reduce food intake can translate into improved body-weight management requires specific study. This idea is supported by the analysis of the 1999 to 2002 National Health and Nutrition Examination Survey (NHANES) data, which show that bean consumers have significantly lower body weights and lower risks for having an increased waist sizes and being obese (44). A significant reduction in body weight from a summary of pulse-intervention studies was reported in an earlier meta-analysis, although its focus was on blood lipids (45). A more focused examination of pulse consumption and body weight comes from studies that have combined them with energy restriction intended to produce weight loss. The earliest study to do this was in adults with type 2 diabetes who consumed an energy-restricted diet including approximately 1.5 cups of legumes per day (some soybeans and green beans were included) for 3 weeks and did not experience any significant weight loss relative to controls (46). In contrast, Abete et al (47) compared energy-restricted diets high in legumes, protein or fatty fish for 8 weeks in obese men and *did* find that body weight significantly decreased in all groups, with a greater magnitude in the legume and protein groups. Further, another 8-week intervention by Hermsdorff et al (48) found that the addition of 4 weekly servings of pulses in an energy-restricted diet resulted in significantly greater reductions in body weight and body mass index.

Pulse-intake studies have also demonstrated reductions in body weight without energy restriction. For example, in a 3-month intervention, Jenkins et al (28) included 1 cup of pulses per day as a major part of a low-GI diet without energy restriction in adults with type 2 diabetes and found that body weights and waist circumferences were significantly reduced, and were reduced to greater extents than in those consuming the high wheat-fibre comparison diet. In a previously mentioned study, overweight and obese adults randomized to pulse consumption (5 cups of pulse/week in various dishes) or to dietary counselling so as to reduce energy intake, and after 8 weeks found that the pulse consumption significantly reduced energy intake and waist circumferences (but not body weight) to an extent comparable to the energy restriction (15).

The role of pulses in body-weight management was most recently examined in a 2016 meta-analysis of 21 studies and 940 participants (49). The overall analysis found a modest but significant reduction in body weight (–0.34 kg; 95% CI: –0.63, –0.04 kg) with diets containing approximately 1 serving (132 g) of pulses per day, compared with diets without pulses over a median duration of 6 weeks. The significant body-weight reduction was observed both in negative energy-balance studies ($n=4$) that intended weight loss (–1.74 kg; 95% CI: –3.19, –0.30 kg) and in neutral energy-balance studies ($n=17$) that intended weight maintenance (–0.29 kg; 95% CI: –0.56, –0.03 kg). Although the magnitude of body-weight reduction observed was modest, the authors highlighted that inclusion of pulses in the diet do not lead to weight gain.

Overall, there is growing evidence from a variety of acute and chronic studies that pulses are able to improve satiety, decrease food intake and contribute to body-weight management. These effects can contribute to diabetes prevention and management and are recognized by the WHO, which includes legumes in its dietary recommendations for reducing obesity and overweight.

Conclusions

The studies we reviewed demonstrated consistently that pulse-based diets result in substantial improvements in glycemic control, reduction of blood lipids and regulation of body weight. Acute consumption of three-quarters to 1 cup of pulses significantly attenuates PBGR, and long-term consumption of 5 cups per week generally improves FBG, FBI and A1C levels in persons with type 2 diabetes. Similarly, the intake of two-thirds of a cup per day of pulses can effect considerable lowering of blood cholesterol, thereby reducing CVD risk, a major complication of diabetes. Risk for obesity is also lowered because pulse consumption improves satiety, reduces food intake and regulates body weight. However, there is need for further studies to strengthen the available evidence and to address the following questions: 1) what is the minimum effective dose of pulses required to attenuate PBGR significantly?; 2) what is the minimum effective dose of pulses required to improve glycemic control significantly in the long term?; 3) how consistent is the second-meal effect and what factors must be considered in its application to dietary management of persons with type 2 diabetes? 4) how does processing affect the PBGR-lowering property of pulses?

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Author Contributions

All authors contributed substantially to the conception, acquisition and interpretation of data and were involved in drafting and revising the article critically for important intellectual content. DDR coordinated preparation of the manuscript and prepared the final version. All authors gave final approval of the version to be published.

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