Nutrition Bulletin

REVIEW

DOI: 10.1111/nbu.12235

An update of the evidence relating to plant-based diets and cardiovascular disease, type 2 diabetes and overweight

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Abstract

Recent findings from meta-analyses, European cohorts and randomised controlled trials (RCTs) evaluating the relationship between plant-based dietary regimes (*i.e.* those with an emphasis on plant foods, such as vegetarian, vegan, Mediterranean or combination diets), and the incidence of, or risk factors for, cardiovascular disease (CVD), type 2 diabetes (T2D) and obesity are considered in this review. Evidence from meta-analyses of epidemiological studies indicates that those following plant-based dietary regimes have around 20–25% lower risk of developing CVD and a similar reduced risk of developing T2D. Evidence from RCTs indicates that those following plant-based dietary regimes have lower total cholesterol, low-density lipoprotein-cholesterol and blood pressure, and modest reductions in inflammatory and endothelial markers. Higher intake of plant foods has been associated with lower incidence of obesity, lower BMI and smaller waist circumference. For weight loss, it seems that following a plant-based dietary regime results in weight loss comparable to that achieved on conventional reduced calorie diets, but with better overall weight management. The totality of evidence indicates there are benefits for cardiovascular health, risk of developing T2D and weight management from following a plant-based dietary regime. From a nutritional perspective, plant-based diets tend to be lower in saturated fatty acids, higher in unsaturated fatty acids and fibre, and lower in energy density than typical 'Western' diets. These qualities may be at the core of the health benefits reported and/or it may be simply a greater proportion of plant foods in the diet that is beneficial in its own right.

Keywords: cardiovascular health, diabetes, healthy eating, obesity, plant-based eating, weight management

Introduction

It is well recognised that good nutrition is one of the key factors in maintaining health and wellbeing. Traditionally, nutrient guidelines have focused on the nutrients required to meet physiological needs for normal metabolic function and growth, as well as support overall good health, while contributing to reduced risk of diet-associated diseases. Over the last decade or so, with sound nutritional science remaining at the core of dietary guidelines, there has been increased interest in the environmental credentials of

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the diet. It was partly this interest in more sustainable diets that has led people to look more at plant-based diets, which are not only consistent with supporting good health but also beneficial for the planet (Green *et al.* 2015).

During the last few years, evidence has been accumulating about the benefits of plant-based eating. While the initial emphasis of research related to nutrient adequacy, latterly evidence is accumulating with respect to disease risk and weight management. The purpose of this review is to update previous findings (Garton & Harland 2011; Harland & Garton 2015), which focussed more broadly on plant-based eating and a wide range of health issues, and to direct attention to the more recent literature that specifically relates to cardiovascular disease (CVD), type 2 diabetes (T2D) and weight management. In the 5 years since our 2011 scientific literature review on plant-based eating, there has been a large increase in studies reporting broadly in this subject area but there is still a need for further studies relating to plant-based diets *per se* (Garton & Harland 2011). The findings from these earlier reviews indicate that plant-based diets are associated with improved blood lipid profiles and modest effects on blood pressure and weight management; all of which could contribute to reduced risk of developing CVD, T2D and obesity (Harland & Garton 2015). The objective of this review was to determine the extent to which these earlier findings have been supported by recent studies and to improve understanding of whether dietary regimes based on plant foods lead to positive impacts on health that reduce the risk of developing CVD, T2D and obesity.

Methods

One of the key challenges in this research area is identifying literature that specifically relates to plant-based diets. The reasons for this are twofold: there is no precise definition of a plant-based diet and the concept of plant-based eating is relatively new, with few authors using the term in their papers. While many people associate this way of eating with being vegetarian, this is not necessarily the case. The term 'vegetarian' itself encompasses a variety of eating patterns – some include variable amounts of animal foods such as eggs, dairy products and fish, while others eat none of these. Plant-based eating does not typically exclude all animal products, instead it places the emphasis on plant foods: fruit and vegetables, plant proteins, oils, nuts and seeds, and wholegrain carbohydrates. Rather than meat being the focus of the diet, it is considered more as a condiment, and plant foods are the major source of nutrition. This eating pattern is in line with the World Cancer Research Fund (WCRF) recommendation that two-thirds of a meal should be plant-based foods and one-third should be animal products (WCRF/AICR 2007).

Early studies investigating the benefits of plant-based diets tended to define this way of eating according to the relative absence of meat in the diet, including complete avoidance of animal foods (vegans). However, the health benefits of plant-based diets were found to not only relate to the lack of animal foods in the diet but also due to the increased quantity of plant-based foods (Dwyer 1999). Consequently, more recent studies consider plant-based diets not as vegan or vegetarian but as diets with an emphasis on plant foods and an inclusion of low-fat dairy foods, fish and a modest intake of lean meat. A further way of examining plant-based eating is to use dietary pattern analysis rather than to solely focus on individual foods. In this context, studies evaluating Mediterranean Diet (MedD) patterns or healthy eating indices can be useful as they are largely plant-based and usually include modest amounts of fish, dairy products and little meat (Martinez-Gonzalez *et al.* 2002).

A search using the term 'plant-based' was undertaken using the PubMed database (www.ncbi.nlm.nih.gov/pubmed/). This term was used in previous reviews of published research (Garton & Harland 2011; Harland & Garton 2015) and found to generate few papers; nonetheless, this was the starting point for this update covering the period from January 2015 to August 2016. This search was then supplemented by secondary searches using the terms 'vegetarian' or 'vegan' or 'Mediterranean Diet' or 'DASH' and 'heart disease' or 'diabetes' or 'obesity' or 'overweight'. In addition, traditional risk factors relevant to each condition (CVD, T2D and obesity), for example high blood cholesterol, low-density lipoprotein-cholesterol (LDL-C), blood pressure (BP), blood glucose and waist circumference (WC), were also used as search terms to identify relevant studies. Information relating to emerging risk factors, such as insulin resistance, abdominal obesity, elevated triglycerides (TAG), low high-density lipoprotein-cholesterol (HDL-C) and inflammatory markers, was also identified.

Excluded papers were those detailing animal or *in vitro* studies, case studies, case reports, letters and non-systematic reviews. Also excluded were studies where the key objective was not related to plant-based diets, vegetarian/vegan diets or MedD. Included studies were meta-analyses and systematic reviews, human observation studies and randomised controlled trials (RCTs), which evaluated the effect of a suitably defined plant-based diet and at least one of the measures of one of the disease or disease risk factors detailed above, and were conducted in broadly healthy subjects (*e.g.* studies in subjects who had mildly elevated cholesterol, blood lipids, blood pressure or blood glucose were included, as were studies in the overweight and obese and those demonstrating symptoms of the metabolic syndrome). An updated consolidated database was established, which included 269 new references – these are the main focus in this narrative review, although where appropriate, reference is made to the whole consolidated database of 1370 references.

Overview of evidence identified

Of the 269 new references identified, only 12 included the term 'plant-based' in the title and only one was highly relevant to this review (Eichelmann *et al.* 2016). The lack of specific plant-based studies is a weakness of this update and, as a result, the definition of plant-based eating continues to be less precise than desirable. The main sources of new information were meta-analyses and prospective cohort studies assessing either vegetarian or MedD eating patterns. The largest number of new studies related to MedDs and, as such, European populations are disproportionately represented in this analysis. There were few new RCTs, with most including vegetarian or MedD interventions, or meta-analyses of these studies.

Nutrient intake of those adopting plant-based dietary regimes

Contrary to the typical 'Western' style of eating, plant-based eating patterns are associated with diets that are low in total fat and saturated fatty acids (SFA), good sources of unsaturated fatty acids (UFA) (both omega-3 and omega-6 fatty acids) and high in fibre, antioxidant vitamins and phytonutrients (Craig & Mangels 2009; Harland & Garton 2015; Sobiecki *et al.* 2016). As such, these eating patterns appear to be in line with international and national dietary recommendations, including the WCRF (WCRF/AICR 2007), the Dietary Guidelines for Americans (DGA) (USDA 2015), American Dietetic Association (ADA) (Craig & Mangels 2009) and the UK *Eatwell Guide* (PHE 2016).

The characteristics of a plant-based diet have been examined in a number of European population studies; for full details see Harland and Garton (2015). For example, the Oxford arm of the *European Prospective Investigation into Cancer and Nutrition* (*EPIC*) study (Davey *et al.* 2003; Sobiecki *et al.* 2016) compared the dietary intake of meat eaters (n = 33 883), fish eaters (n = 10 110), lacto-ovo-vegetarians (n = 18 840) and vegans (n = 2596). It was observed that, on average, SFA intake in vegans was approximately 5% of food energy (E), less than half that of meat eaters (10–11%E). SFA intakes in fish eaters and vegetarians were intermediate, at approximately 9%E. In addition, polyunsaturated fatty acid (PUFA) and fibre intake were highest in the vegan group, followed by fish eaters and vegetarians.

The *Prevención con Dieta Mediterránea* (*PREDIMED*) study demonstrates how the nutritional quality of the diet improves as more plant foods are included (Martínez-González *et al.* 2014). This study used a parallel group, multicentre and RCT design to test the effects of two Mediterranean-type diets on CVD risk factors compared with a control (low-fat) diet. Approximately 7500 men and women (aged 55–80 years with established risk factors for heart disease but who were free of CVD at baseline) were assigned to one of three diets – a MedD (high in fruit, vegetables, legumes and nuts and low in red meat, dairy and refined grains) supplemented with extra-virgin olive oil; or a MedD supplemented with mixed nuts (approximately 30 g/day); or a control diet based on the American Heart Association low-fat diet. Using dietary data from 7216 participants, a pro-vegetarian eating pattern was developed based on 12 food groups. Fruit, vegetables, nuts, cereals, legumes, olive oil and potatoes were positively weighted, while animal fats, eggs, fish, dairy products and meats or meat products were negatively weighted and a total score for the diet developed. Total scores ranged from 12–60, with higher scores reflecting higher adherence to a pro-vegetarian food pattern and associated with lower total fat and SFA intakes and higher PUFA and fibre intakes.

Studies in developed countries have found vegetarians to have greater intakes of several micronutrients, including thiamin, folate, vitamin C, carotene, potassium and vitamin E, than the general population (Davey *et al.* 2003; Haddad & Tanzman 2003; Farmer *et al.* 2011). Thus, including more plant foods in the diet could help improve intakes of micronutrients lacking in certain population groups across Europe (Mensink *et al.* 2013). However, concerns are regularly expressed about the micronutrient adequacy of plant-based diets, specifically in relation to zinc, iron, vitamin B_{12}, vitamin D and calcium (Tucker 2014; Pawlak *et al.* 2016).

Cardiovascular disease and plant-based diets

Much of the recent data on the effects of plant-based diets on CVD risk come from studies of vegetarian or semi-vegetarian diets (which allow the inclusion of fish and/or up to two servings of chicken per week) (Appleby & Key 2015; Wang *et al.* 2015; Dinu *et al.* 2016) or MedDs (Bloomfield *et al.* 2016; Garcia *et al.* 2016; Godos *et al.* 2016; Liyanage *et al.* 2016; Nissensohn *et al.* 2016).

A systematic review and meta-analysis of observational data from consumers of a vegetarian or vegan diet, including 86 cross-sectional studies and ten prospective cohorts, has recently been published (Dinu *et al.* 2016). The objective was to assess the association between vegetarian/vegan diets and risk factors for chronic diseases, disease incidence and mortality – including from cardio-cerebrovascular diseases. Retained studies were subject to a number of meta-analyses to compare the health of vegetarians and vegans to that of omnivores. An analysis of seven prospective cohorts identified a significantly reduced relative risk (RR) of incidence of and/or mortality from ischaemic heart disease (IHD) in vegetarians to that of omnivores (RR 0.75; 95% CI: 0.68, 0.82; $P < 0.001$). Non-significant heterogeneity ($I^2 = 35\%$; $P = 0.16$) was reported. As part of their review, Dinu *et al.* (2016) also conducted a meta-analysis of data relating to cerebrovascular diseases (incidence/mortality). In this case, risk of incidence of cerebrovascular diseases in vegetarians and omnivores was found to not differ significantly (RR 0.93; 95% CI: 0.78, 1.10).

In further meta-analyses in this study, data on risk of IHD from the different study cohorts were compared (Dinu *et al.* 2016). Of particular interest are the Adventist cohorts, who have a more restrictive lifestyle than society at large. As such, there has been considerable discussion as to the representativeness of these population groups to Western populations as a whole. This was examined in relation to IHD risk in this article. The subanalysis of vegetarians, whether from Adventist ($n = 3$) or non-Adventist ($n = 4$) cohorts, resulted in RRs for IHD of 0.70 (95% CI: 0.60, 0.82) and 0.79 (95% CI: 0.71, 0.88) respectively, and although the Adventist cohorts appeared to have a lower risk of IHD, the difference between groups was not statistically significant (Dinu *et al.* 2016).

In an earlier review of the same topic, five prospective cohort studies were combined to compare the death rates from common diseases of vegetarians with those of non-vegetarians with similar lifestyles (Key *et al.* 1999). In this sample of 76 172 men and women aged 16–89 years, there were 8330 deaths after an average follow-up period of 10.6 years. Death from heart disease was almost a quarter lower in vegetarians than in non-vegetarians. This effect was more pronounced in those who had followed a vegetarian diet from a younger age and for more than 5 years (Key *et al.* 1999). Also, in comparison with regular meat eaters, mortality from IHD was 20% lower in occasional meat eaters, 34% lower in people who ate fish but not meat, 34% lower in lacto-ovo-vegetarians and 26% lower in vegans (Key *et al.* 1999).

For those following a plant-based dietary regime, the reduction in IHD risk of 20–24% was consistent between the two reviews despite different inclusion criteria, populations and definition of plant-based dietary regimes (Key *et al.* 1999; Dinu *et al.* 2016). Details of the main studies that have evaluated the association between plant-based dietary regimes (both vegetarian and MedD) and cardiovascular heath are detailed in Table 1 (Key *et al.* 1999; Appleby *et al.* 2016 ; Crowe *et al.* 2011; Buckland *et al.* 2009; Key *et al.* 2003; Key *et al.* 2009; Lopez-Garcia *et al.* 2014; Martínez-González *et al.* 2014). In a recent review of RCTs comparing MedDs to control diets, individual studies were pooled to create summary estimates for the RR of the diets on major vascular events and vascular deaths (Liyanage *et al.* 2016). Five studies ($n = 9950$) were identified which when pooled showed a protective effect of a MedD against major vascular events (RR 0.69, 95% CI: 0.55, 0.86) and stroke (RR 0.66; 95% CI: 0.48, 0.92) but not cardiovascular mortality (RR 0.90: 95% CI: 0.72, 1.11). In the original *PREDIM7ED* study, the objective was to identify the association between *a priori*-defined pro-vegetarian food pattern and all-cause mortality in participants at high CVD risk (Martínez-González *et al.* 2014). Three dietary interventions were tested: a MedD supplemented with extra-virgin olive oil (EVOO), a MedD supplemented with nuts and a control diet (advice on a low-fat diet). During a median time of 4.8 years, hazard ratios (HR) of cardiovascular events were 0.70 (95% CI: 0.53, 0.91) for the MedD + EVOO and 0.70 (95% CI: 0.53, 0.94) for the MedD + nuts, compared to the control group (Martinez-Gonzalez *et al.* 2015). Significant improvements in classical and emerging CVD risk factors also supported a favourable effect of both MedD regimes on blood pressure,

Table 1 The impact of plant-based diets in mainly European populations on various measures of cardiovascular disease risk

Author	Study/country	Diets studied	*n* at start	Follow-up (years)	Age and gender	Outcome measure	Results (95% CI)
Cohorts based on UK populations							
Appleby *et al.* (2016)	Two cohorts, UK	Regular meat eaters ≥5 times/week, low meat eaters, fish eaters, vegetarians (including vegans)	60 310	15	20–89 M/W	HR IHD	Regular meat (reference) 1.00 Low meat 0.93 (0.76, 1.15) Fish 1.00 (0.75, 1.34) Vegetarians and vegans 0.99 (0.79, 1.23)
Key *et al.* (1999)	Five cohorts, UK	Non-vegetarian, vegetarian	76 172	10.6	16–89 M/W	DRR IHD	Non-vegetarian (reference) 1.0 Vegetarian 0.76 (0.62, 0.94)
Key *et al.* (2003)	EPIC Oxford, UK	Non-vegetarian, vegetarian	56 000	3–9	20–89 M/W	DRR IHD	Non-vegetarian (reference) 1.00 Vegetarian 0.75 (0.41, 1.37)
Key *et al.* (2009)	EPIC Oxford update, UK	Non-vegetarian, vegetarian	64 234	8–14	20–89 M/W	DRR IHD	Non-vegetarian (reference) 1.00 Vegetarian 0.81 (0.57, 1.16)
Key *et al.* (2003)	Oxford Vegetarian, UK	Non-vegetarian, vegetarian	11 000	18–26	20–89 M/W	DRR IHD	Non-vegetarian (reference) 1.00 Vegetarian 0.86 (0.67, 1.12)
Key *et al.* (2003)	Health Food Shoppers Study, UK	Non-vegetarian, vegetarian	11 045	16–20	20–89 M/W	DRR IHD	Non-vegetarian (reference) 1.00 Vegetarian 0.85 (0.71, 1.01)
Crowe *et al.* (2011)	EPIC cohorts in eight countries: Denmark, Germany, Greece, Italy, The Netherlands, Spain, Sweden, UK	F&V intake	313 074	8.4	20–89 M/W	RR IHD mortality	<3 portions F&V per day (reference) 1.00 > 8 portions F&V per day 0.78 (0.65, 0.95) For every 1 portion F&V 0.96 (0.92, 1.00)
Mediterranean Diet studies							
Buckland *et al.* (2008)	Cohort, five centres, Spain	Mediterranean Diet	41 078	10.4	29–69 M/W	CHD events	Low adherence MDS (reference) 1.00 High adherence MDS 0.60 (0.47, 0.77) Per 1-unit increase MDS 0.94 (0.91, 0.97)
Martínez-González *et al.* (2014)	PREDIMED cohort, Spain	Pro-vegetarian food pattern compliance score 12–60 points	7216	4.8	60–80 M/W	HR mortality	Compliance score <30 points (reference) 1.00 ≥ 40 points 0.59 (0.40, 0.88)
Lopez-Garcia *et al.* (2014)	Health Professionals Follow-up/Nurse Health Study cohort, US	Mediterranean Diet	6137 M 11 278 W	7.7 for M; 5.8 for W	30–75 M/W	RR CVD mortality	Lowest quintile MDS (reference) 1.00 Highest quintile 0.85 (0.67, 1.09)

DRR, death rate ratio; HR, hazard ratio; RR, relative risk; CHD, coronary heart disease; CVD, cardiovascular disease; F&V, fruit and vegetables; IHD, ischaemic heart disease; M, men; W, women; MDS, Mediterranean Diet Score.

insulin sensitivity, lipid profiles, lipoprotein particles, inflammation, oxidative stress and carotid atherosclerosis, indicating that a vegetable-based MedD rich in UFA and polyphenols can play a role in dietary management of CVD risk. The quality of systematic reviews/meta-analyses relating to Mediterranean-style diets published prior to 2015 was recently assessed, (Huedo-Medina *et al.* 2016). This assessment was conducted according to the Assessment of Multiple Systematic Reviews (AMSTARMedSD) quality scale that aims to establish contemporary methodological quality standards (Shea *et al.* 2007). Twenty-four reviews were included in the assessment, in which 8–75% of the AMSTARMedSD items were satisfied. These figures indicate high variability in quality of reporting, and it was found that those articles published in higher-impact journals had greater quality scores. At a minimum, 60% of the 24 reviews did not disclose full search details or apply appropriate statistical methods to combine study findings. To have greater confidence in the findings from meta-analyses, the authors recommend that future studies should follow methodological quality standards and include more statistical modelling results.

While these studies of vegetarian, vegan and MedDs provide only a proxy for plant-based diets (where meat may be consumed in small quantities), there is consistency in the findings – those who consume more plant foods and less or no meat tend to have improved heart health and a lower death rate from heart disease and possibly stroke. The extent of reduction in CVD risk is typically around 20% (RR: 0.59–0.99), see Table 1, although the methodological limitations of this data, as detailed above, should be taken into consideration.

Cardiovascular risk factors and plant-based diets

A recent meta-analysis compared the effects of vegetarian diets with omnivorous diets on CVD risk factors (Wang *et al.* 2015). Eleven trials were included in the meta-analysis and results showed that vegetarian diets significantly lowered blood concentrations of total cholesterol (TC), LDL-C and HDL-C; the pooled estimated changes were −0.36 mmol/l (95% CI: −0.55, −0.17; $P < 0.001$), −0.34 mmol/l (95% CI: −0.57, −0.11; $P < 0.001$), and −0.10 mmol/l (95% CI: −0.14, −0.06; $P < 0.001$), respectively. Vegetarian diets did not significantly affect blood TAG concentrations, with a pooled estimated mean difference of 0.04 mmol/l (95% CI: −0.05, 0.13; $P = 0.40$). If findings from the recent study by Wang *et al.* (2015) are compared to the largest meta-analysis conducted to date on the effect of plant-based eating on blood lipid profiles (Ferdowsian & Barnard 2009), it can be seen that TC and LDL-C levels were found to be reduced in both studies. The Ferdowsian and Barnard (2009) analysis included 27 studies (14 RCTs and 13 observational studies) and found that, compared to baseline values, primarily plant-based and ovo-lacto-vegetarian dietary interventions were associated with decreases in TC and LDL-C (by about 10–15%), vegan dietary interventions by about 15–25% and combination dietary interventions (vegetarian diets with additional fibre, soya and nuts – the Portfolio Diet) by about 20–35%. However, the majority of studies of plant-based diets in the Ferdowsian and Barnard (2009) study were associated with a reduction in TAG while the Wang *et al.* (2015) study of vegetarian diets was not significant overall.

A meta-analysis of RCTs assessed the effects of MedD regimes on emerging risk factors of CVD – endothelial function and inflammation (Schwingshackl & Hoffmann 2014). Seventeen RCTs ($n = 2300$) were included. High adherence compared to low adherence to MedD regimes resulted in a significant increase in flow-mediated dilatation weighted mean difference (WMD) 1.86%, (95% CI: 0.23, 3.48; $P = 0.02$) and adiponectin WMD 1.69 mg/ml (95% CI: 0.27, 3.11; $P = 0.02$), while the WMDs in high-sensitive C-reactive protein −0.98 mg/l (95% CI: −1.48, −0.49; $P < 0.0001$), interleukin-6 −0.42 pg/ml (95% CI: −0.73, −0.11; $P = 0.008$) and intracellular adhesion molecule1 −23.73 ng/ml (95% CI: −41.24, −6.22; $P = 0.008$), were significantly lower. Overall, the results provide evidence that a MedD decreases inflammation and improves endothelial function, which may be factors that contribute more broadly to the benefits of plant-based diets on CVD.

The effect of combination dietary interventions on cardiovascular health

Portfolio Diets are low-fat diets based on plant foods, specifically those plant foods or ingredients proven to reduce blood cholesterol, for example soya (Anderson *et al.* 1995; Harland & Haffner 2008), nuts (Kris-Etherton *et al.* 2008; Sabate *et al.* 2010), soluble fibre-containing foods, such as oats and psyllium (Ortiz *et al.* 2012; Nishi *et al.* 2014), and plant stanols and sterols (Abumweis *et al.* 2008; Demonty *et al.* 2009). Latterly, the diets also have included a source of monounsaturated fatty acids (MUFA) in the form of rapeseed or sunflower oil (Labonte *et al.* 2013). These various foods, or food components, included in the Portfolio Diet, typically reduce LDL-C by 3–5%, with higher reductions for the plant stanols and sterols (~9%). For further details, see the review by Harland (2012).

The different combinations of plant foods studied have been reviewed in detail previously (Harland 2012). In brief, there are approximately 12 Portfolio studies ($n = 725$), conducted over a 4–80 week period in clinical settings and in the community. In the short-term studies, cholesterol reduction in response to the Portfolio Diets was typically highly statistically significant ($P < 0.001$), with LDL-C being approximately 20–35% lower than the control diets (Ferdowsian & Barnard 2009). Four recently reported community-based interventions with plant-based diets (Chainani-Wu *et al.* 2011; Mishra *et al.* 2013; Morton *et al.* 2014; Macknin *et al.* 2015) have been summarised in Harland and Garton (2015); all studies resulted in a reduction in LDL-C (range 7–13%). This is not dissimilar to the findings from a free-living community Portfolio Diet study where LDL-C was reduced by 13%, less than half of that reported for clinical studies (Jenkins *et al.* 2006).

Another combination dietary intervention is the *Dietary Approaches to Stop Hypertension (DASH)* diet, which was originally developed to help manage hypertension. In essence, it is a plant-based diet rich in fruit, vegetables and low-fat dairy foods, with a focus on wholegrain cereals, poultry, fish and nuts, and is low in fats, red meat and sugars-containing foods and beverages (Svetkey *et al.* 1999). A large study validating the effects of the *DASH* diet on hypertension, found that the *DASH* intervention resulted in a 7.1 mmHg reduction in systolic blood pressure (SBP) in participants without hypertension and 11.5 mmHg in participants with hypertension, compared to control group (Sacks *et al.* 2001). Recently, a systematic review and meta-analysis of *DASH* studies conducted from inception to December 2013 was published (Siervo *et al.* 2015). Studies were included if they used a *DASH* diet plan, employed a RCT design and measured risk factors including SBP, diastolic blood pressure (DBP), glucose, HDL-C, LDL-C, TAG or TC. A total of 20 articles reporting data for 1917 participants were included in the meta-analysis. The duration of interventions ranged from 2–24 weeks. Compared to control, the *DASH* diet was found to result in significant decreases in SBP (−5.2 mmHg; 95% CI: −7.0, −3.4; $P < 0.001$), DBP (−2.6 mmHg; 95% CI: −3.5, −1.7; $P < 0.001$), blood concentrations of TC (−0.20 mmol/l; 95% CI: −0.31, −0.10; $P < 0.001$) and LDL-C (−0.10 mmol/l; 95% CI: −0.20, −0.01; $P = 0.03$). Changes in both SBP and DBP were greater in participants with higher blood pressure or BMI at baseline. These changes predicted a reduction of approximately 13% in the Framingham 10-year risk score for CVD. Another meta-analysis has been conducted in 17 RCTs with a total of 2561 participants (Saneei *et al.* 2014). In this study, the meta-analysis showed that, compared to control, the *DASH* diet significantly reduced SBP by 6.74 mmHg (95% CI: −8.25, −5.23) and DBP by 3.54 mmHg (95% CI: −4.29, −2.79); both $P < 0.0001$. However, in both meta-analyses, a marked degree of heterogeneity was reported with I^2 values being 78.1% and 56.7%, respectively. RCTs involving hypertensive subjects following *DASH* diets, which included energy restriction, showed a significantly greater decrease in blood pressure compared to unrestricted energy intake (Saneei *et al.* 2014).

The various meta-analyses indicate that *DASH* diets, which include a high proportion of plant and low-fat dairy foods and are low in salt content, reduce both SBP and DBP in adults, although there is variation in the extent of the fall in blood pressure in different subgroups (Saneei *et al.* 2014; Siervo *et al.* 2015). A meta-analysis of observational studies evaluating the effect of long-term adherence to the *DASH* diet has demonstrated that modification of CVD risk factors can affect the incidence of CVD, stroke, coronary heart disease (CHD) and heart failure (HF) (Salehi-Abargouei *et al.* 2013). Six studies met the inclusion criteria for this meta-analysis and adherence to the *DASH* diet, and RR of these conditions was reported. Following a *DASH* diet was found to significantly reduce risk of CVD (RR = 0.80; 95% CI: 0.74, 0.86), CHD (RR = 0.79; 95% CI: 0.71, 0.88), stroke (RR = 0.81: 95% CI: 0.72, 0.92) and HF (RR = 0.71: 95% CI: 0.58, 0.88) all $P < 0.001$ (Salehi-Abargouei *et al.* 2013).

Two combination diet types, Portfolio and *DASH*, were compared in a recent RCT (Jenkins *et al.* 2015). In this study, 241 participants with hyperlipidaemia were randomised to consume for 24 weeks either a *DASH*-type diet, which was considered the control ($n = 82$), or a Portfolio Diet that included soya protein, viscous fibres and nuts ($n = 159$). Compared to the *DASH* control diet, at 24 weeks, the Portfolio Diet resulted in reduced mean DBP of 1.8 mmHg (95% CI: 3.2, 0.4; $P = 0.013$) and mean arterial blood pressure of 1.9 mmHg (95% CI: 3.4, 0.4; $P = 0.015$). Nuts, soya and viscous fibre intake were all related negatively to change in mean arterial pressure (rho = −0.15 - −0.17; $P \leq 0.016$) as was urinary potassium (rho = −0.25; $P = 0.001$). The reported reduction in LDL-C was −0.8 mmol/l ($P > 0.05$) in the Portfolio Diet, which was 0.5 mmol/l greater than the *DASH*-type diet ($P < 0.0001$).

Recent epidemiological studies provide insight into disease risk reduction associated with plant-based dietary regimes. The findings are largely derived from MedD studies, and these are mostly in agreement with earlier data from *EPIC* cohorts and others [*e.g. the Oxford Vegetarian Study, Adventist Health Study-2, Heidelberg Study* (Key *et al.* 1999b)]. Among these cohort studies, a common theme emerges: those following plant-based dietary regimes have a lower risk of developing CVD or cardiovascular mortality and lower risk of developing, or incidence of, T2D. Typically, this reduced risk of CVD incidence/mortality is around 20–25% (Schwingshackl *et al.* 2015; Dinu *et al.* 2016). In these studies, the changes observed in risk factors of CVD, such as reductions in TC and LDL-C (Ferdowsian & Barnard 2009; Dinu *et al.* 2016) and SBP and DBP (Saneei *et al.* 2014), provide insight into the mechanisms underpinning the effects on CVD incidence/mortality, although the effect of plant-based diets on TAG remains to be fully established.

Plant-based diets and type 2 diabetes

In the recently published literature on T2D, there are few epidemiological studies that refer to plant-based diets *per se*. Most studies have calculated a Mediterranean Diet score (MDS) or subdivided the population into various types of vegetarian diets, as a basis to evaluate the associations between diet and the development of T2D or risk factors for T2D (Dominguez *et al.* 2013). The MDS uses ten components to express the agreement with the Mediterranean dietary pattern: seven 'desirable' (vegetables, legumes, fruit, nuts, cereals, fish and olive oil), two 'undesirable' (meat and dairy) and one 'in moderation' (alcohol). Higher scores reflect higher adherence.

Recently, a meta-analysis summarised the effects of MedD adherence on the risk of developing T2D (Schwingshackl *et al.* 2015). The retained studies published between 2007 and 2014 were predominantly cohort studies ($n = 8$) and one RCT, involving subjects aged ≥19 years ($n = 122\,810$), which used dietary records to assess MDS and recorded the development of T2D; see Table 2 (Schwingshackl *et al.* 2015). Comparing the group with the highest MDS to the lowest, the pooled RR for the development of T2D was 0.81 (95% CI: 0.73, 0.90; $P < 0.0001$, $I^2 = 55\%$). Sensitivity analysis including only long-term studies confirmed the results of the primary analysis (pooled RR 0.75; 95% CI: 0.68, 0.83; $P < 0.00001$, $I^2 = 0\%$). Publication bias was assessed using the Egger regression test, and there was no evidence of substantial bias ($P = 0.25$).

The *EPIC* cohorts provide an insight into the incidence of T2D among sectors of European populations that have been subdivided by various measures relating to the consumption of plant foods [*e.g.* by protein source (animal or plant), fruit, vegetable, flavonoid and fibre intake] (Zamora-Ros *et al.* 2013; van Nielen *et al.* 2014; Cooper *et al.* 2015). The *EPIC-InterAct* is a case–cohort study that aims to investigate how genetic and potentially modifiable lifestyle and behavioural factors, particularly diet and physical activity, interact to influence the risk of developing T2D (InterAct Consortium 2015). The *EPIC* data indicate no strong association between the type of protein consumed, whether derived from animals or plants, and the risk of developing T2D. However, higher dietary fibre intake was associated with lower risk of developing T2D, after adjustment for lifestyle and dietary factors. For example in the *EPIC-InterAct* meta-analysis ($n = 19$ cohorts), dietary fibre intake was associated with a lower risk of developing T2D, (HR 0.82; 95% CI: 0.69, 0.97); however, the association was attenuated and no longer statistically significant after adjustment for BMI (InterAct Consortium 2015). The summary RRs for developing T2D per 10 g/day increase in fibre intake were 0.91 (95% CI: 0.87, 0.96) for total fibre; 0.75 (95% CI: 0.65, 0.86) for cereal fibre; 0.95 (95% CI: 0.87, 1.03) for fruit fibre; and 0.93 (95% CI: 0.82, 1.05) for vegetable fibre (InterAct Consortium 2015). Data from the *PREDIMED* study also indicate a reduced incidence of T2D and insulin sensitivity among those following a MedD (de Lorgeril 2011; Martinez-Gonzalez *et al.* 2015).

Three cohorts from the Seventh-Day Adventists in North America provide further information on the relationship between dietary practices and risk of developing T2D. As a group, they have many cultural, lifestyle and ethical differences to Western populations and, as such, care should be taken in interpreting the relevance of this data to Western populations. The most recently reviewed data are primarily derived from the *AHS-2* cohort (22 434 men and 38 469 women). Participants were grouped as vegan, lacto-ovo-vegetarian, pesco-vegetarian, semi-vegetarian or non-vegetarian (Orlich & Fraser 2014). The authors

Table 2 The relative risk (RR) of type 2 diabetes in relation to highest vs. lowest adherence to a Mediterranean Diet. Data from eight prospective cohort studies and one randomised controlled trail (n = 122 810) published between 2007 and 2014 and reviewed by Schwingshackl *et al.* (2015)

Author	Country/study	Study type	*n* at start	Follow-up (years)	Age gender	Quality score*	RR T2D highest vs. lowest MedD score (95% CI)
Abiemo *et al.* (2013)	US, MESA	Cohort	5390	6	45–84 M/W	7	1.09 (0.80, 1.49)
Brunner *et al.* (2008)	England, Whitehall II	Cohort	7731	15	35–69 M/W	7	0.94 (0.68, 1.30)
De Koning *et al.* (2011)	US, HPFS	Cohort	41 615	≥20	n.d. M	9	0.75 (0.66, 0.85)
Salas-Salvado *et al.* (2014)	Spain, PREDIMED	RCT	3541	4.1	55–80 M/W	4†	0.70 (0.54, 0.91)
InterAct Consortium (2011)	All EPIC except Greece and Norway	Cohort	16 154	4.4	25–70 M/W	9	0.88 (0.79, 0.98)
Martínez-González *et al.* (2008)	Spain, SUN	Cohort	13 380	3.2	20–29 M/W	8	0.17 (0.04, 0.72)
Mozaffarian *et al.* (2007)	Italy	Cohort	8291	11.34	20–90 M/W	7	0.65 (0.49, 0.86)
Rossi *et al.* (2013)	Greece, EPIC	Cohort	22 295	4	20–80 M/W	9	0.88 (0.78, 0.99)
Tobias *et al.* (2012)	US, NHS II	Cohort	4413	14	24–44 W	8	0.76 (0.60, 0.96)
Overall pooled data			122 810	3.3–20	20–90 M/W		0.81 (0.73, 0.90)

*Newcastle–Ottawa Scale quality score.

†JADAD score; M, men; W, women; n.d., not determined; MedD, Mediterranean Diet; RCT, randomised controlled trial.

concluded that vegetarian dietary patterns were associated with lower prevalence and incidence of T2D, lower BMI, lower prevalence of the metabolic syndrome and its component factors, lower prevalence of hypertension and lower all-cause mortality. These findings indicate a link between vegetarian dietary patterns and good health, for further details see Harland and Garton (2015).

Plant-based diets and risk factors of type 2 diabetes

A systematic review and meta-analysis of controlled clinical trials of ≥4 week duration examining the association between vegetarian diets and glycaemic control in T2D has recently been conducted (Yokoyama *et al.* 2014). The review assessed studies involving participants aged >20 years, vegetarian diet as intervention and mean difference in HbA1c and/or fasting blood glucose levels as outcome measures. Six studies met the inclusion criteria ($n = 255$, mean age 42.5 years). Consumption of a vegetarian diet was associated with a significant reduction in HbA1c levels (−0.39% point; 95% CI: −0.62, −0.15; $P = 0.001$; P for heterogeneity = 0.389), and a non-significant reduction in fasting blood glucose concentration (−0.36 mmol/l; 95% CI: −1.04, 0.32; $P = 0.301$; P for heterogeneity = 0.710), compared with consumption of comparator diets. The authors concluded that consumption of vegetarian diets is associated with improved glycaemic control in T2D.

A systematic review and meta-analysis has been conducted among the *DASH* studies that measured risk factors of T2D (Shirani *et al.* 2013). Indices of glycaemic control, such as fasting blood glucose (FBG), serum fasting insulin levels and homeostatic model assessment of insulin resistance (HOMA-IR) were used. Twenty studies that examined the effect of *DASH* diet on these indices were assessed, included studies measuring FBG ($n = 9$), fasting insulin ($n = 7$) and HOMA-IR ($n = 4$). The meta-analysis showed that the *DASH* diet significantly reduced fasting insulin concentrations (mean difference −0.15; 95% CI: −0.22, −0.08; $P < 0.001$). Subgroup analysis based on the study period showed that the *DASH* diet significantly reduced fasting insulin levels when adhered to for more than 16 weeks (mean difference −0.16; 95% CI: −0.23, −0.08; $P < 0.001$). The analysis did not show an effect on FBG and HOMA-IR. The authors concluded that the *DASH* dietary pattern may lead to an improvement in insulin sensitivity, independent of weight loss, and may play a role in glycaemic control in long-term interventions.

Looking at the evidence-base as a whole, a reduction in risk of developing T2D appears to be well established for those following a MedD (pooled RR 0.81), see Table 2, Schwingshackl *et al.* (2015) and Martinez-Gonzalez *et al.* (2015). A recent review of prospective studies concluded that where there was higher adherence to a MedD, a 20–23% reduced risk of developing T2D was found (Esposito *et al.* 2016), and in another recent report, high adherence to a

MedD was found to be associated with a 30% reduction in T2D risk ($P < 0.05$) (Salas-Salvado *et al.* 2016). Also, RCTs of the MedD were found to reduce glycosylated haemoglobin levels by 0.30–0.47% (Esposito *et al.* 2016). These findings strengthen the earlier reported associations between plant-based eating regimes and T2D.

The mechanisms by which the MedD exerts its cardiometabolic benefits in T2D are mostly proposed to be anti-inflammatory and antioxidative (Esposito *et al.* 2016; Turner-McGrievy *et al.* 2015b). Indeed, measures of inflammatory status seem to improve when a plant-based diet is followed, indicating that these factors may contribute to the mechanisms of action of chronic disease risk reduction (Schwingshackl & Hoffmann 2014; Eichelmann *et al.* 2016). The totality of the evidence suggests a benefit of reduced risk of developing T2D when following plant-based diets, which may confer at least a 20% reduction in risk (Schwingshackl & Hoffmann 2015; Salas-Salvado *et al.* 2016).

Metabolic syndrome and plant-based diets

The term 'cardiometabolic risk' is an umbrella term for a comprehensive list of existing and emerging factors that predict the development of CVD and/or T2D (Leiter *et al.* 2011). As discussed above, plant-based diets appear to reduce risk factors for both CVD and T2D. In addition, a number of recent reviews also point to a reduction in the symptoms of metabolic syndrome when subjects follow a plant-based dietary regime (Garcia *et al.* 2016; Godos *et al.* 2016). In a meta-analysis of 35 RCTs, two prospective studies and 13 cross-sectional studies the effect of adopting a Mediterranean-style diet on a number of metabolic risk factors was assessed (Garcia *et al.* 2016). The study found that a Mediterranean-style diet had beneficial effects on several metabolic risk factors, specifically WC, TAG, glucose, SBP and DBP. In a second meta-analysis of observational studies (eight cross-sectional and four prospective studies), adherence to a MedD was assessed in 33 847 healthy individuals and 6342 individuals with metabolic syndrome (Godos *et al.* 2016). High adherence to a MedD was associated with a reduced risk of metabolic syndrome (RR: 0.81; 95% CI: 0.71, 0.92), and inverse associations for WC, blood pressure and low HDL-C levels were significant in this analysis ($P < 0.05$). Thus, adopting a plant-based diet is one approach, among others (*e.g.* increased physical activity, smoking cessation), that may help manage cardiometabolic risk.

Obesity, weight management and plant-based diets

There is concern at the rising incidence of obesity among young people. The relationship between dietary patterns and overweight and obesity in young people has been examined using 1804 randomly selected adolescents aged 12.5–17.5 years (47% males) from the *HELENA* study European database (Lin *et al.* 2015). Total animal and plant protein intakes were assessed, and associations with anthropometry and serum biomarkers were examined. Total average protein intake was above recommendations [EFSA Panel on Dietetic Products Nutrition and Allergies (NDA) 2012] and was found to be significantly lower in underweight subjects and higher in those who were obese; the direction of the relationship was reversed after adjustments for bodyweight. Inverse associations of plant protein intake with BMI z-score and body fat percentage (BF%) were reported, while BMI and BF% were positively associated with energy intake as a percentage of animal protein. The authors suggested that higher proportions of plant protein intake may play a role in preventing obesity among European adolescents, but further studies are required (Lin *et al.* 2015).

In adults, studies have indicated that greater compliance with a MedD is associated with the prevention of overweight/obesity (Buckland *et al.* 2008; Roswall *et al.* 2014). Also, a review of long-term studies in vegetarians and vegans has indicated a lower prevalence of overweight and obesity compared with non-vegetarians/vegans from a similar background (Appleby & Key 2015). Vegetarians were found to have a lower BMI than otherwise comparable non-vegetarians, with differences typically in the region of 1–2 kg/m^2 across all adult age groups with vegans generally having the lowest BMI (Appleby & Key 2015).

A systematic review and meta-analysis of interventions that measured the effect of plant-based diets on obesity-related inflammatory biomarkers was recently conducted (Eichelmann *et al.* 2016). The biomarkers of inflammatory status assessed were C-reactive protein (CRP), interleukin-6 (IL-6), tumour necrosis factor-alpha (TNF-a), soluble intercellular adhesion molecule 1 (sICAM), leptin, adiponectin and resistin. Twenty-nine publications met the meta-analysis inclusion criteria ($n = 2689$). Consumption of plant-based diets was associated with a reduction in the mean concentrations of CRP (−0.55 mg/l; 95% CI: −0.78, −0.32), IL-6 (−0.25 ng/l; 95% CI: −0.56, 0.06)

($P < 0.05$) and, to a lesser extent, sICAM (−25.07 ng/ml; 95% CI: −52.32, 2.17); however, in all cases, the I^2 values were >90%, indicating a high degree of uncertainty in these relationships. Plant-based diets were found to have no effects on levels of TNF-α, resistin, adiponectin and leptin. The authors concluded that plant-based diets are associated with improved obesity-related inflammatory profiles, which could have a therapeutic role in reducing the risk of chronic disease (Eichelmann *et al.* 2016).

The relationship between weight management or weight loss and plant-based diets would ideally be assessed in RCTs of medium-to-long duration (≥12 months). However, many studies are of shorter duration (≥4 week) and these types of studies have recently been reviewed (Barnard *et al.* 2015). A meta-analysis of 15 RCTs examining the effect on bodyweight of vegetarian diets (without energy intake limitations) compared to conventional weight-loss regimes was conducted (Barnard *et al.* 2015). Prescription of vegetarian diets was associated with a mean weight change, compared to the control diets, of −3.4 kg (95% CI: −4.4, −2.4; $P < 0.001$) in an intention-to-treat analysis and −4.6 kg (95% CI: −5.4, −3.8; $P < 0.001$) in a completer analysis. Greater weight loss was reported in studies with higher baseline bodyweights, smaller proportions of female participants, older participants, or longer durations and in studies in which weight loss was a goal. Moderate heterogeneity was indicated ($I^2 = 52.3\%$; $P = 0.10$).

A systematic review has been conducted to assess whether RCTs evaluating the previously discussed *DASH* diet, which comprises ingredients known to be beneficial in weight management, improve measures of obesity, bodyweight, BMI and WC. Thirteen studies were retained for meta-analysis, of which ten measured bodyweight, six measured BMI and two measured WC (Soltani *et al.* 2016). Results indicated that, compared to a control diet, adults on a *DASH* diet lost more weight in 8–24 weeks (−1.42 kg; 95% CI: −2.03, −0.82) (see Fig. 1), and had bigger reductions in BMI in 8–52 weeks (−0.42 kg/m^2; 95% CI: −0.64, −0.20) and WC in 24 weeks (−1.05 cm; 95% CI: −1.61, −0.49). Low caloric *DASH*-type diets led to even greater weight reduction when compared with other low-energy diets.

In a recent RCT, 63 overweight and obese adults (BMI 25–49.9 kg/m^2) were randomly assigned to one of four plant-based diets (vegan, vegetarian, pesco-vegetarian, semi-vegetarian) or an omnivore diet (Moore *et al.* 2015). Primary outcomes at 2 and 6 months included dietary adherence (24-hour dietary recalls), weight loss and changes in animal product intake (assessed by mg cholesterol intake). Adherence status, dietary acceptability and impact of diet preference on adherence were also measured. No differences were found in dietary adherence among the groups

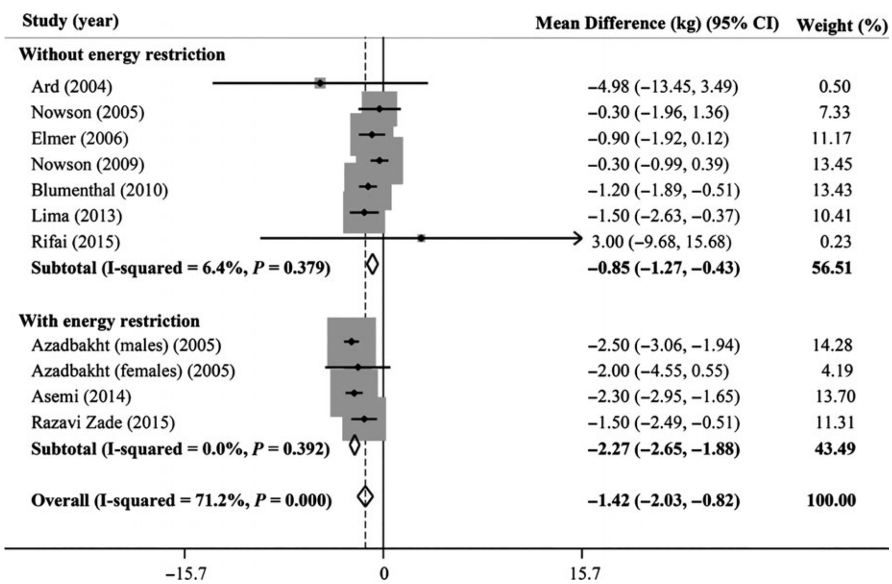

Figure 1 Forest plot of randomised controlled clinical trials illustrating weighted mean difference in weight change (kg) between the DASH and control groups for eleven studies and with subgroup analysis based on the energy restriction (random effects model). Figure from Soltani *et al.* (2016) and is published here with permission.

and dietary preference had no impact on adherence at 6 months. One of the key findings was that at 6 months non-adherent vegan/vegetarian participants had lost significantly more weight than non-adherent omnivore participants (−6.0 kg ± 6.7% vs. 0.4 kg ± 0.6%; $P = 0.04$). This suggests that merely the instruction to follow a vegan or vegetarian diet, which resulted in only partial compliance, had a greater impact on weight loss and animal product intake than providing instruction to reduce animal product intake. In a further report of this study, it was identified that 50 (79%) participants completed the study (Turner-McGrievy *et al.* 2015a). Following an intention-to-treat analysis, the linear trend for weight loss across the groups was significant at both 2 and 6 months ($P < 0.01$). At 6 months the weight loss in the vegan group (−7.5% ± 4.5%) was significantly different from the omnivorous (−3.1% ± 3.6%; $P = 0.03$), semi-vegetarian (−3.2% ± 3.8%; $P = 0.03$), and pesco-vegetarian (−3.2% ±3.4%; $P = 0.03$) groups. Vegan participants decreased their fat and SFA intake more than the pesco-vegetarian, semi-vegetarian and omnivorous groups at both 2 and 6 months ($P < 0.05$).

Similar findings were reported when volunteers ($n = 39$) followed a plant-based so-called Eco-Atkins diet, compared to a more conventional low-carbohydrate, high-animal protein weight-reducing diet (Jenkins *et al.* 2014). Weight loss at 6 months was significantly greater with the Eco-Atkins diet, at −6.9 kg compared to −5.8 kg in the control group ($P = 0.047$). In addition, participants had significantly better blood lipid profiles and reduced BP following the Eco-Atkins diet relative to the control diet, and the 10-year CHD risk was found to be significantly reduced by 2% ($P = 0.001$) by the Eco-Atkins diet (Jenkins *et al.* 2014).

Evidence from cohort studies also indicates that those following a plant-based regime (vegetarian or MedD) have a lower BMI (Dinu *et al.* 2016), less weight gain over time, lower WC and lower incidence of obesity (Roswall *et al.* 2014; Appleby & Key 2015). The indication is that plant-based dietary regimes are at least as effective as more conventional omnivorous weight-loss regimes. In addition, where there is lower adherence to a dietary regime, vegetarian diets seem to outperform conventional approaches and lead to substantial weight loss (Moore *et al.* 2015). Issues known to be of importance in weight management are energy density (WHO 2007) and the effect of the diet on satiety. Evidence points to plant-based diets having a lower energy density than animal-based diets, probably related to higher fibre intake and lower SFA intake (Sobiecki *et al.* 2016). The effect of energy density on weight loss was assessed in a systematic review of 17 studies in adults and six cohort studies in children and adolescents, conducted by the Dietary Guidelines Advisory Committee (Rafael *et al.* 2012). It was concluded that adult dietary patterns that are relatively low in energy density improve weight loss and weight maintenance. Furthermore, the authors of an extensive systematic review of 1517 papers, examining the relationship between macronutrient intake and long-term weight gain, concluded that there was 'probable evidence for high intake of dietary fibre predicting less weight gain' (Fogelholm *et al.* 2012).

Fibre, particularly soluble fibres, has been shown to contribute to feelings of fullness and improved satiety, which may be central to their role in weight management (Howarth *et al.* 2001). In addition, most fibre-containing foods have a low glycaemic index, which may be important in glucose and insulin management (Mann 2007). Moderating insulin production or improving insulin sensitivity can promote less fat storage and hence less obesity (Wolfram & Ismail-Beigi 2011). An additional benefit of high-fibre diets may be the bacterial population which it encourages, with recent evidence suggesting a role for gut microbiota in metabolic regulation and, in particular, insulin resistance and adipose tissue inflammation (Janssen & Kersten 2016).

Conclusions

Recent data indicate that plant-based diets tend to be lower in SFA and higher in UFA with a better overall fat profile (Sobiecki *et al.* 2016). Furthermore, they tend to have a higher fibre content and be lower in energy density. These characteristics of plant-based diets may be central to the benefits that have been identified in relation to the development of CVD, T2D and obesity. However, as yet, it is not known which components of plant-based diets contribute most to their health benefits and it may well be that the sum of the parts is of more relevance than focussing on the individual components.

Recent epidemiological evidence supports earlier data which indicate that those following plant-based dietary regimes have around 20% lower risk of CVD incidence/mortality (Schwingshackl *et al.* 2015; Dinu *et al.* 2016), and at least a similar reduced risk of developing T2D (Martinez-Gonzalez *et al.* 2015; Schwingshackl *et al.* 2015). In those demonstrating a high compliance to a MedD, the reduction in risk of developing T2D is higher – in the region of 30% (Salas-Salvado *et al.* 2016). There is evidence from both RCTs and observational studies that those following plant-based dietary regimes have improved blood lipid profiles, including lower levels of TC and LDL-C (Wang *et al.* 2015; Dinu *et al.* 2016), and reduced BP and inflammatory and endothelial markers (Ruiz-Canela *et al.* 2015; Eichelmann *et al.* 2016; Garcia *et al.* 2016). However, less data are available on the relationship between plant-based eating and cerebrovascular diseases, incidence and mortality and stroke, and findings to date are equivocal (Dinu *et al.* 2016); although meta-analyses of a limited number of cohort studies indicate that following *DASH*-type diets can result in around a 20% reduction in incidence of stroke (Salehi-Abargouei *et al.* 2013; Kontogianni & Panagiotakos 2014).

Epidemiological data point to an association between the long-term adoption of plant-based dietary regimes and lower levels of obesity, lower BMI and WC (Roswall *et al.* 2014; Appleby & Key 2015; Park *et al.* 2016), with findings from RCTs indicating that better blood glucose management, lower HbA1c levels and improvements in inflammatory and endothelial markers may contribute to these effects (Yokoyama *et al.* 2014).

There is limited evidence to indicate that the benefits of plant-based dietary regimes are on a continuum, from vegan to omnivore (Appleby & Key 2015; Dominguez *et al.* 2015) but, nonetheless, this review indicates that a move towards more plant-based diets may be beneficial to cardiovascular health, and reduce the incidence of T2D, obesity and metabolic syndrome.

Source of funding

This review has been produced independently by JIH and LG who have received no funding for undertaking this research. JIH and LG act as independent nutrition consultants and receive funding from a variety of sources.

Conflict of interest

The views expressed are those of the authors alone.

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