BIBLIOGRAPHIC INFORMATION SYSTEM

Journal Full Title: Journal of Biomedical Research & Environmental Sciences

Journal NLM Abbreviation: J Biomed Res Environ Sci

Journal Website Link: https://www.jelsciences.com

Journal ISSN: 2766-2276

Category: Multidisciplinary

Subject Areas: Medicine Group, Biology Group, General, Environmental Sciences

Topics Summation: 128

Issue Regularity: Monthly

Review Process type: Double Blind

Time to Publication: 7-14 Days

Indexing catalog: Visit here

Publication fee catalog: Visit here

DOI: 10.37871 (CrossRef)

Plagiarism detection software: iThenticate

Managing entity: USA

Language: English

Research work collecting capability: Worldwide

Organized by: SciRes Literature LLC

Manuscript should be submitted in Word Document (.doc or .docx) through

Online Submission

form or can be mailed to support@jelsciences.com

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JOURNAL OF BIOMEDICAL RESEARCH & ENVIRONMENTAL SCIENCES
issn: 2766-2276
SUBJECT AREA(S): NUTRITION | METABOLIC SYNDROMES
DOI: 10.37871

REVIEW ARTICLE

Implications of Plant Foods in Weight Management: Focus on Metabolic Health

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ABSTRACT

Plant foods are important component of human diet and they are excellent source health-promoting compounds, such as amino acids, dietary fibers, complex carbohydrates, unsaturated fatty acids, as well as minerals and vitamins which have been shown to increase vitality and subsequently reduce risk of chronic disease. Importantly, eatable plants despite relatively low caloric value are nutrient-dense foods, which are rich in various phytochemicals, such as polyphenols, that have been found to be beneficial for improving metabolic health, in particular lowering systemic inflammation, increasing antioxidant capability and promoting weight loss. To date, epidemiological evidence consistently demonstrated a beneficial impact of adopting plant-based dietary lifestyle characterized by increased intake of whole unprocessed foods, including fresh vegetables and fruits, whole grains, pulses and legumes as well as nuts and seeds, in expense of processed meats, refined carbohydrates and added sugar foods, have potential to reduce risk of high burden diseases, such type 2 diabetes, obesity or cardiovascular disease. Consequently, to assess the most applicable composition of plant-based diets for achieving metabolic improvements, nutritional value of consumed plants should be evaluated. Therefore, accounting for differences in phytochemical content of various fruits, vegetables, grains, pulses, nuts and seeds the main aim of this literature review is to assess the recent clinical evidence of their contribution to weight management, and reduction of risk factors implicated in development of chronic conditions, such as cardiovascular diseases, diabetes or obesity.

Introduction

Obesity has become one of the most important public health problems affecting more than 650 million adults worldwide. Excessive body weight, in particular overweight and obesity, has been strongly associated with metabolic health disturbances that include type 2 diabetes mellitus; cardiovascular diseases, obstructive sleep apnea; depression; as well as cancer [1]. Not surprisingly, various lifestyle interventions, including changes to dietary patterns and exercise, were evaluated as the first line treatment for metabolic disturbances and obesity prevention.

An interest in developing optimal diets for metabolic health and weight management have been increasing not only among researchers and nutritionists, but also among the general public. According to the recent evidence, many popular diets can induce weight loss, however for only few of them actually demonstrated a long-term effectiveness confirmed by clinical evidence. For instance, among most popular weight loss diets, only low-carbohydrate diets (-8.73 kg at 6-month follow-up and -7.25 kg at 12-month follow-up) and low-fat diets (-7.99 kg at 6-month follow-up and -7.27 kg at 12-month follow-up) seems to be effective [2]. Although, it may suggest that both low carbohydrate and low-fat diets have a similar effect on weight loss, low carbohydrate diets seems to result in a smaller amount improvements in the lipid profile, characterized by lower reductions in LDL

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DOI: 10.37871/jbres1618

Submitted: 21 October 2022

Accepted: 29 November 2022

Published: 30 November 2022

Keywords

- Weight management
- Plant foods
- Obesity
- Metabolic syndrome
- Antioxidants
- Dietary fiber

MEDICINE GROUP

NUTRITION METABOLIC SYNDROMES

VOLUME: 3 ISSUE: 11 - NOVEMBER, 2022

How to cite this article: Jurek JM. Implications of Plant Foods in Weight Management: Focus on Metabolic Health. 2022 Nov 30; 3(11): 1440-1450. doi: 10.37871/jbres1618, Article ID: JBRES1618, Available at: https://www.jelsciences.com/articles/jbres1618.pdf

and increase in HDL cholesterol fractions, compared to low fat and Mediterranean diet [3]. Noteworthy, clinical evidence demonstrated that consumption of vegetarian diets over a median duration of 18 weeks can promote significantly more weight loss when compared to non-vegetarian diets, with the weighted mean difference, of -2.02 kg; however with a more reduction following consumption of a vegan diet (-2.52 kg) and, to a lesser extent, for lacto-ovo-vegetarian diets (-1.48 kg). The weight loss for subjects with follow-up of < 1 year was greater (-2.05 kg) than those with follow-up of ≥ 1 year (-1.13 kg) [4]. Interestingly, a cholesterol-lowering a vegan type of diet, named as Portfolio diet, recommending a daily consumption of 2 g of plant sterols, 50 g of nuts, 10-25 g of soluble fibers from plant foods, and 50 g of soy protein, while eliminating meat, fish and seafood, as well as other animal products, appears to have a relatively and non-significant effects on weight loss [5].

Although vegetarian dietary plans can vary greatly, ranging from the exclusion of meat products to the raw vegan plan, which only includes raw vegetables, fruits, nuts, seeds, legumes, and sprouted grains, the overall trend aiming to reduce consumption of animal products, in particularly red meat, processed meat foods and high fat diary, in expense of increased intake of fresh whole foods of plant origin, such as fruit, vegetables and whole grains may help to significantly reduce the risk of developing many common diseases, including heart disease, type 2 diabetes, cancer [6] (Table 1).

The health benefits attributed to plant based foods are attributed to their rich content of bioactive ingredients, with specific biological effects on the human physiology. Depending on the type of food of plant origin, the amount of particular health-promoting nutrients can vary. For example, fruits and vegetables are especially rich in minerals, vitamins and dietary fibres, whenever nuts and seeds can be a good source of essential unsaturated fatty acids as well as antioxidants. On the other hand, starchy vegetables, pulses and whole grains are provide complex carbohydrates additionally rich in different types of dietary fibres, as well as minerals and vitamins, that ultimately help to maintain glucose homeostasis [7] (Table 2).

Table 1: A summary of results of the clinical studies assessing effect of certain plant-based diets on weight management [6].

Intervention	Population (n)	Duration	Main Findings	Mean Change in Weight Status
Low-fat vegetarian diet	Premenopausal women (*n = 51*)	2 menstrual cycles	Reductions in weight and BMI. Changes in weight were associated with changes in energy intake.	Weight: -2,5 kg; BMI: -0,9 kg/m^2
Low-fat vegan diet	Overweight, postmenopausal women (*n = 64*)	14 weeks	Significant weight reduction in the vegan group, no significant difference between the vegan and National Cholesterol Education Program groups.	Weight: Vegan: -5,8 kg ± 3.2 kg Control: -3,8 kg ± 2.8 kg
Low-fat vegan diet with low GI	Type 2 diabetes patients (*n = 49*)	22 and 74 weeks	Sustained weight loss in both the vegan and American Diabetes Association groups, no significant difference between the groups.	Weight: Vegan: -4,4 to -6,8 kg Control: -3,0 kg to -4,9 kg.
Low-fat vegan diet	Overweight and/or with previous diagnosis of type 2 diabetes (*n = 68*)	22 weeks	Significant weight reductions only in the intervention group.	Weight: Vegan: -5,1 kg ± 0.6 kg; Control: +0,1 kg ± 0.6 kg; BMI: Vegan: -2,0 kg/m^2 Control: -0 kg/m^2
Lacto-vegetarian diet	Normal weight, non-smoking (*n = 20*)	3 months	Mean weight reduction among the participants	Weight: Diet intervention: -2 kg
Low-salt, raw vegan diet rich in lactobacteria	Women with fibromyalgia, of which 66% were overweight (*n = 18*)	3 months	Significant weight reductions in the intervention group.	BMI: Vegan: -4 kg/m^2 Control: -0 kg/m^2
Low-fat, high-carbohydrate vegan diet	Overweight (*n = 38*)	16 weeks	Reductions in weight and BMI only in the intervention group, which was associated with increased carbohydrate and fiber intake.	Weight: Vegan: -6,5 kg; Control: +0,57 kg BMI: Vegan: -2,0 kg/m^2
Low-fat vegan diet	Overweight and/or with previous diagnosis of type 2 diabetes (*n = 94*)	18 weeks	Weight reductions in the intervention group, with significant difference between the groups.	Weight: Vegan: -2,9 kg to -4,3 kg Control: -0,06 kg to -0,08 kg BMI: Vegan: -1,04 kg/m^2 to -1,5 kg/m^2 Control: -0,01 kg/m^2 to 0.02 kg/m^2

Low-fat diets with low GI: vegan (n=12), vegetarian (n=13), pesco-vegetarian (n=13), semi-vegetarian (n=13) or omnivore (n=12)	Overweight *(n = 58)*	2 and 6 months	Significantly greater weight loss among non-adherent vegan/vegetarian participants compared with non-adherent omnivore participants. There was no difference in weight loss among participants who adhered to their diet, regardless of the diet.	Weight (loss %): Diet intervention: -6,0 ± 6.7% Control: -0,4 ± 0.6%
Low-calorie lacto-ovo-vegetarian diet, or Low-calorie Mediterranean diet	Overweight omnivores with a low-to-moderate cardiovascular risk *(n = 100)*	2 x 3 months	Significant weight reductions in both groups. No significant difference between the groups	Weight: Lacto-ovo diet: -1,88 kg; Med. diet: -1,77 kg; BMI: Lacto-ovo diet: -0,64 kg/m^2 Med. diet: -0,67 kg/m^2
Very low-fat vegetarian diet, followed by exercise and stress management classes	Postmenopausal women with cardiovascular disease *(n = 25)*	1 week	Significant reductions in BMI in the intervention group compared with the control group	Weight (after 12 months): Vege diet: -3,9 kg Control: -0,06 kg BMI (after 24 months): Vege diet: -1 kg/m^2 Control: -0 kg/m^2
Low-fat vegan diet	Overweight, postmenopausal women *(n = 31)*	14 weeks	Significantly greater weight reduction in the intervention group compared with the National Cholesterol Education Program group after 1 and 2 years	Weight: Vegan: -4,9 kg (1 year); -3,1 kg (2 year) Control: -1,8 kg (1 year); -0,8 kg (2 year)
Low-fat diets with low GI: vegan *(n = 12)*, vegetarian *(n = 13)*, pesco-vegetarian *(n = 13)*, semi-vegetarian *(n = 13)* or omnivore *(n = 12)*	Overweight *(n = 50)*	2 and 6 months	Significantly greater weight loss in the vegan group compared to the pesco-vegetarian, semi-vegetarian and omnivore groups.	Weight (% loss): -7,5% vegan -6,3% vegetarian -3,1% omnivore
Low-fat whole-food plant-based diet	Overweight or obesity and at least one of the following diagnosis of type 2 diabetes, ischemic heart disease, hypertension or hypercholesterolemia *(n = 33)*	12 weeks	Significant weight reductions in weight and BMI in the intervention group compared with the control group	Weight: low fat diet: -12,1 kg (6 months) -11,5 kg (12 months) BMI: low fat diet -4,4 kg/m^2 (6 months) -4,2 kg/m^2 (12 months)

Table 2: Examples of plant foods along with bioactive compounds and their proposed effects on human health [7].

Bioactive Compound(s)	Example of Foods	Proposed Health Effects
Omega-3 fatty acids DHA, EPA and ALA	Algae, seaweeds Flaxseed	Reduce risk of heart disease and mental disorders Reduce inflammation Improvement immune function
Carotenoids: β-carotene, lycopene, lutein	Carrot Kale Sweet Pepper Tomatoes Mango	Anti-cancer properties Supports eye health
Resveratrol	Grape Red wine Berries Pecans	Reduce risk of diabetes, cardiovascular disease and dementia
Polyphenols	Coffee Tea Raw cocoa Fresh fruit Berries Beans	Reduce risk of cancer, obesity, diabetes, cardiovascular disease and dementia Reduce inflammation
Phytosterols, Phytostanols	Fresh fruit Fresh vegetables Peanuts Nuts and seeds Whole grains Legumes	Lowers cholesterol

Owing that composition of plant-based diets can vary significantly in their composition, along with noticeable differences in the nutritional value of fruits, vegetables, grains, pulses, nuts and seeds; there is growing interest in the metabolic health benefits associated with particular food types [8]; therefore the main aim of this literature review is to assess the recent clinical evidence of commonly consumed plant foods with particular focus on weight management, and reduction of risk factors implicated in development of chronic conditions, such as cardiovascular diseases, diabetes or obesity.

Fruits and Vegetables

Diets high in fruits and vegetables are widely recommended for their health-promoting properties. Fruits and vegetables include a diverse group of plant foods that vary greatly in content of energy and nutrients, including dietary fibers, vitamins and minerals, as well as various phytochemicals, which acting as antioxidants, phytoestrogens, and anti-inflammatory agents support human health at various stages of life [8]. Results obtained from recent meta-analysis of cohort studies, indicate that intake of approx. 5 servings per day of fruit and vegetables, or 2 servings of fruit and 3 servings of vegetables, was associated with the lowest mortality, interestingly, a higher intake than 5 servings was not associated with additional risk reduction. In comparison with the reference level of 2 servings a day, daily intake of 5 servings of fruit and vegetables was associated with reduced hazard ratios for total mortality, CVD disease, cancer and respiratory disease. Higher intakes of certain fruits and vegetables, including green leafy vegetables, non-starchy vegetables, cruciferous vegetables, citrus fruit, vitamin C rich and β carotene rich fruit and vegetables, were associated with lower total mortality, whereas a higher intake of starchy vegetables was not associated with a lower risk of mortality. Intakes of fruit juices and potatoes were not associated with total and cause-specific mortality [9], which was explained by their higher glycemic load, previously associated with elevated risks of major chronic diseases [10], as well as body weight gain and increase risk of type 2 diabetes [11,12].

Nevertheless, certain processing methods may negatively influence on nutritional value of plant foods. In most cases, fruits and vegetables are often not consumed in the raw form but may be cooked, fried, or combined with other ingredients prior to consumption. For example, a boiled potato is a nutrient-dense food and a fried potato (fries) may contribute a substantial amount of fat and sodium to the diet. Also, home-cooking methods, such as blanching, boiling, microwaving, and steaming, may impact on the content of certain vitamins (β-carotene, vitamin C, vitamins E and vitamin K) in vegetables. For instance, microwaving can lead to the higher retention of vitamin C, while boiling causes the most loosest; whereas microwave cooking caused the least loss of vitamin K in spinach and chard [13]. Therefore, considering health benefits, it is recommended to consume fruit and vegetable in their raw or minimally processed form [14].

Beetroot and physical activity

Consumption of 140 ml serving of beetroot juice can significantly increase the lifted weight in the full squat exercise compared with the placebo drink during the first routine of exercises. Interestingly, intake of a beetroot juice also improved the ventilatory efficiency in the group of well-trained men conducting resistance aerobic exercises [15].

Tomato, kale and leafy greens and skin condition

Dietary supplementation with tomato extract rich in carotenoids, such as lycopene (20 mg) after 12 weeks was more effective in protecting skin against UV radiation compared to placebo, whereas an equal lutein dose (20 mg) demonstrated a smaller effect [16]. Interestingly, these levels of carotenoids can be achieved through diet, which for 20 mg of lutein would be equal to 200 to 400 g portion of kale (or other leafy green vegetables such as spinach and parsley); and for 20 mg lycopene equal to 200 to 400 g canned tomatoes.

Grapes

Grapes and their products, including wine and juice are rich sources of antioxidants, such as resveratrol, a polyphenolic compound with has been shown to bring favorable effects for diabetes management [17], by increasing insulin sensitivity, reducing oxidative stress and modulating energy expenditure within the muscles [18]. Interestingly, a pilot clinical trial on trans-resveratrol supplementation in the Diabetic Foot Syndrome (DFS) in type 2 diabetics newly diagnosed diabetic foot ulcers, indicated that 50 mg of trans-resveratrol taken twice a day after 60 days was effective in lowering markers of diabetic ulcer size compared to placebo [19].

Recent evidence demonstrated that intake of grape-based products, being rich in potent antioxidant, resveratrol, can support cardiometabolic health

A 1-year long supplementation with a resveratrol-rich grape products, containing 8 mg of resveratrol improved the inflammatory and fibrinolytic status in patients at high cardiovascular disease risk (i.e., with diabetes or hypercholesterolemia). This has been observed as significant decrease in inflammatory markers, CRP (-26%), TNF-α (-19.8%), plasminogen activator inhibitor type 1 (-16.8%), and IL-6/IL-10 ratio (-24%), followed by increase in anti-inflammatory cytokine IL-10 (19.8%) [20]. Supplementation with resveratrol (250 mg/day) along oral hypoglycemic treatment for a period of 3 months significantly improved systolic blood pressure in patients with type 2 diabetes [21], whereas intake of 1 g a day of

resveratrol over 45 days significantly decreased systolic blood pressure in diabetics patients [22]. Beneficial effects have been also observed for improved glycemic control. Combining resveratrol (250 mg/day) supplementation with oral hypoglycemic treatment for a period of 3 months significantly improved the mean glycated Haemoglobin A1C in patients with type 2 diabetes [21]. Supplementation with 500 mg dose of trans-resveratrol 3 times daily for 90 days significantly decreased the area under the curve of insulin, and total insulin secretion compared to placebo group in the group of patients with metabolic syndrome [23]. A short-term supplementation with 1 g a day of resveratrol after 45 days significantly fasting blood glucose and glycated Haemoglobin A1C and insulin levels, as well as improved insulin resistance, when compared to the baseline levels of diabetic patients [22]. Additionally, high antioxidant content of grapes may support weight loss process, as intake of a 500 mg dose of trans-resveratrol 3 times daily for 90 days significantly decreased BMI and fat mass indices in individuals with metabolic syndrome compared to placebo group [23].

Berry fruits

Consumption of fruits, particularly berries, citrus and cherries over at least a week may provide beneficial effects related to reduced risk of factors associated with development of cardiovascular disease [9]. It has been shown that regular intake of fruits being high in antioxidants, such as berries (e.g., barberry, cranberry, blueberry, raspberry, strawberry) as well as grape and pomegranate can significantly reduce systolic (by 3.68 mmHg) and diastolic blood pressure (by 1.52 mmHg), and further improve endothelium function determined by Circulating Vascular Cell Adhesion Molecule-1 levels [9]. In particularly, blueberries may help to reduce elevated blood pressure. Intake of 38 g of dried blueberry powder after 6 weeks decreased systolic blood pressure in healthy individuals [24]. Similarly, intake of 22 g of blueberry powder after 8 weeks decreased systolic and diastolic blood pressure in hypersensitive women [25], whereas consumption of 50 g a day of freeze-dried blueberries in after 8 weeks decreased systolic and diastolic blood pressure among individuals diagnosed with metabolic syndrome [26]. Interestingly, consumption of a berry meal as purée (150 g) made of bilberries, blackcurrants, cranberries and strawberries with added 35 g of sucrose can improved the glycaemic profile, observed as significant reduction of glucose and insulin concentrations, when compared to the control meal made of the same amount of sucrose and available carbohydrates in water [27].

Furthermore, regular intake of other type of berries, such as strawberries, cranberries, as well as Goji, Macqui and Acai berries, also have been found beneficial for certain health outcomes. For example, Regular intake of cranberry juice for at least week can significantly reduce systolic (by 1.52 mmHg) and diastolic blood pressure (by 1.78 mmHg) [8], as well as decreased as glucose concentrations in apparently healthy individuals [28]. Similarly, intake of strawberry-based drink 2 h before meal, rather than with or 2 h post the meal significantly reduced a postprandial glucose among overweight adults. Interestingly, consumption of strawberries before and after the meal attenuated postprandial glucose without additional insulin, suggesting improved insulin sensitivity [29]. Regular consumption of strawberries also have potential to improve antioxidant status and decrease free radical formation, resultant from their high phytochemical content, including caffeic acid and homovanillic acid, urolithin A and 4-hydroxyhippuric acid [30]. Interestingly, incorporating into a beige diet a 26 g portion of California strawberry powder promoted gut health and weight maintenance, observed as favorable changes in the intestinal microbiota composition, such as increased the abundance of Firmicutes, Verrucomicrobia, Actinobacteria and Bacteroidetes (species related to lean body weight, health and longevity) and decrease in among healthy adults [31].

Benefits for improved cardiometabolic health were also reported for other berry varieties. For instance, consumption of drink 200 ml a day of açaí juice for 4 weeks was significantly increased the concentrations of HDL cholesterol by 7.7% in healthy adults [32], whereas intake of 120 ml serving of goji berry juice standardized for its bioactive content, attributed to Lycium Barbarum Polysaccharides (LBP), being in this case equal to the consumption of approx. 150 g portion of fresh fruit, after 14 days significantly decreased waist circumference in apparently healthy subjects [33].

Berry juices being a potent source of antioxidants can reduce oxidative stress load within the body, arising from metabolic disturbances or intense physical activity. Intake of açai-based smoothie providing in total 694 mg of phenolics along a high-fat meal eaten for breakfast improved vascular function through lowering an acute oxidative status caused by the high fat meal in the group of obese middle-aged men [34], whereas açai-based beverage containing 27.6 mg of anthocyanins per serving, significantly increased time to exhaustion during a short-term high-intensity exercise and reduced metabolic stress induced by exercise in endurance athletes [35]. Furthermore, consumption of 200 ml serving of açaí juice significantly increased a total antioxidant capacity (by 66.7%), determined by catalase (increase in concentration by 275.1%) and glutathione Peroxidase-1 (increase in concentration by 15.3%), while in the same time decreased oxidative stress index by 55.7% when compared to the baseline among healthy adults [32]. Similarly, addition to the low calorie diet a 200 g serving of açaí pulp, after 60 days significantly reduced markers of oxidative stress, determined by 8-isoprostane concentrations in overweight individuals with dyslipidemia [36]. Similarly, supplementation with 162 mg dose of a Delphinol three times a day for the period of 4 weeks decreased oxidative damage, determined by the urinary F2-isoprostanes concentration in

the urine samples provided from apparently healthy adults, overweight individuals, and cigarette smokers [37].

Interestingly, Goji berries have been proposed a potential role in healthy aging Consumption of 28 g portion of Goji berries, five times weekly for 90 days significantly increased the level of carotenoids determined by macular pigment optical density, a biomarker of age-related macular degeneration in the skin samples of middle aged individuals between 45 and 65 years old [38], while a daily consumption of goji berry juice standardized for LBP (120 ml) being in this case equal to the consumption of approx. 150 g portion of fresh fruit, after 14 days increased subjective feelings of general well-being, observed as improved neurological and psychological performance, as well gastrointestinal function in adults [39].

Pulses and legumes

Legumes play an important role in the diet of people around the world as a source of protein and carbohydrates. Although chickpea is one of the most consumed pulses, other varieties, including beans, peas and lentils are a good source of slowly digestible carbohydrate, dietary fiber and proteins all together contributing to lowering the glycaemic-index of the diet. Regular consumption of pulses and legumes bring beneficial effects on human health, in particularly on glycaemic control. Among all pulses, chickpeas seems to lead to the most significant decrease in the fasting blood glucose. Similar effect was also observed for beans, in particular black, white, pinto, red varieties as well as white kidney beans; however, more research is needed to confirm optimal serving for most prominent results [40]. Noteworthy, this effect will largely depend on the type of pulse consumed and whole meal pattern. For example, consumption of pulses, such as chickpeas, lentils, navy beans or yellow peas, as a part of high-glycaemic meal contributes to earlier satiation, lower blood glucose concentrations after the meal and following meal consumed after a later meal, but these effects are specific to pulse type and cannot be explained by their glycaemic properties alone [41].

Pulses and glycaemic control

Low-glycemic index legume diet that included at least 1 cup of legume a day after 3 months, improved glycemic control observed as reduced hemoglobin A1C values by -0.5%. For comparison, the same diet that included a wheat fiber diet reduced HbA1C values by -0.3%, which indicate the greater relative reduction in HbA1C values after the low-glycemic index legume diet than the high wheat fiber diet in the individuals with diabetes [42]. Consistently, results obtained by meta-analysis conducted on 41 randomised controlled experimental trials, involving 1,674 participants, indicated that intake of pulses alone or as part of low-GI or high-fibre diets can help to improve long-term glycaemic control, determined by glycosylated Haemoglobin levels (HbA1C) and its subsequent reduction ranging from 0.58 to 0.77% in patients diagnosed with type 2 diabetes.Similarly, addition of pulse flours into snacks and baking goods may also bring glycemic benefits, as consuming whole pulses. For example, incorporation of pinto bean and chickpea flour (40%) into corn snacks improved postprandial glycemic response, but also increased their nutritional value, by the protein and fiber content, without affecting snack palatability [43].

Incorporation various pules into daily diet has been found beneficial for metabolic health and body weight maintenance in both healthy individuals, as well as those already diagnosed with a chronic conditions. A 3-month long dietary intervention with low- glycemic index legume diet (1 cup of legume of choice a day) reduced coronary heart disease risk for the was -0.8%, also observed by a greater relative reduction in systolic blood pressure when compared to the high wheat fiber diet in individuals with type 2 diabetes [42]. In women with polycystic ovary syndrome, a low-glycemic index pulse-based diet, including meals made with lentils, beans, split peas, and chickpeas, after 16 weeks (4 months) significantly reduced insulin response determined by the oral glucose tolerance test, as well as decreased diastolic blood pressure, triglyceride, LDL cholesterol and total cholesterol/HDL cholesterol in the group following an aerobic exercise training (min. five 45 min long sessions a week). Interestingly, decreased total cholesterol/HDL cholesterol ratio and increased HDL cholesterol was maintained 12 months after the intervention in the group, who received pulse-based diet, may suggest additional benefits for cardio-metabolic health following pulse-based diet [44]. In addition, diets containing pulses with median intake of 132 g a day or ~ 1 serving a day may lead to overall significant weight reduction of -0.34 kg when compared to calorie-restricted and maintenance diets that do not include pulses [45]. Therefore adding pulses, such as beans, peas, chickpeas, lentils in the daily diet can increase satiety for 31% greater satiety without impact on the following meal intake [46].

Whole grains and cereals

Whole grains are a group of unprocessed cereal foods in which the endosperm, germ, and bran are intact, therefore making whole cereals an excellent source of slowly digested complex carbohydrates, being in the same time rich in dietary fibers, vitamins, antioxidants, and phytochemicals (e.g., phenolic compounds, including ferulic acids and cinnamic, beta-glucan, and lignans). Nutritional content of whole grains, which have been reported to play a protective role in many metabolic diseases, such as diabetes, obesity and cardiovascular disease [47]. Consumption of whole grains is inversely associated with risk of metabolic disturbances and development of type 2 diabetes [48]. In particularly, oats have been particular beneficial on glucose control and lipid profiles in type 2 diabetic patients, whereas regular oatmeal intake reduced the acute postprandial glucose and insulin

responses compared with the control meal [49]. Whole grain diet that encourages higher consumption of whole grains as well as include incorporation of several commonly eaten whole grain foods, such as whole grain breakfast cereal, oatmeal, dark bread, brown rice, wheat bran, and wheat germ, was significantly associated with a lower risk of type 2 diabetes [50]. Similarly, incorporation of 100 g of whole grains, such as wheat, rice and oats, into daily diet of pre-diabetic individuals after 8 weeks improved insulin response observed as increased total glucose-stimulated insulin secretion and pancreatic β-cell function, when compared those who consumed diet with refined grains [51].

Oats are particular type of wholegrain food, which gains most attentions, mostly due to its benefit for glycaemic control and improvements in lipid profile. There is a clinical evidence to indicate that diets supplemented with 100 g portion of oats after 30 days can significantly improve fasted plasma glucose, and normalize long-term glycemic control determined by glycosylated Haemoglobin (HbA1C), as well as reduce insulin resistance in overweight diabetics [46]. Incorporation a 100 g portion of oatmeal to diet of patients with diabetes after 12 weeks improved glycemic control, noted as significantly lowered required insulin dose on the third and fourth day of the interventions as compared to the second day. Furthermore, the concentrations of glycated Haemoglobin HbA1C remained reduced four weeks after completion of the oatmeal intervention [52]. Addition of 30 g portion of oat bran a day to a lunch or dinner mean after 4 weeks significantly decreased mean fasting blood glucose and 2 h postprandial glucose concentrations in the group of women with gestational diabetes, as compared to group who did no received oat bran [53]. Similarly, consuming a 27.3 g serving of commercial oat-bran based product (OatWell®22), containing 22% of β-glucans, before a meal of white bread significantly lowered blood glucose levels after meal in healthy humans. Interestingly, in this study for each 1 g of oat β-glucan, there was 4.35% reduction in glucose area under curve, may suggest that consuming an oat bran before meal may help in the management of postprandial glycemia [54]. Incorporation of 30 g serving of oat bran daily for 4 weeks to lunch and dinner meal significantly decreased mean fasting blood glucose and 2 h postprandial glucose concentrations in women with gestational diabetes, compared to females who not added oat bran to their diet [53]. Furthermore, intake of 50 g of oat bran breakfast cereal (8.1 g % of β-glucan) or oat bran bar (6.5 g% β-glucan) significantly lowered glycemic response in individuals with type 2 diabetes. This effect was not observed after intake equal portions of commercial oat bran breakfast cereals (4.4 g% β-glucan) or white bread, suggesting that addition of beta-glucan while reducing GI of foods (in 50 g portion each gram of β-glucan reduced GI by 4 units) may help to reduce postprandial glycemia [55]. In terms of noticeable improvements in the lipid profiles, addition of 40 g of oat bran, however not rice flour to the diet can led to significant reduction in total and LDL cholesterol levels, followed by further decrease in blood glucose concentrations thereby suggesting additional benefit attributed to oat bran for improving symptoms of insulin-resistance [56]. Similarly, consumption of a rich in fiber bread products made with oat bran concentrate (soluble fiber β-glucan content = 22.8% (9 g), total dietary fiber 34 g a day), compared to white bread (total dietary fiber 19 g a day) as part of breakfast, significantly lowered mean total and LDL cholesterol levels, noted as 24% reduction in the LDL:HDL cholesterol ratio [57].

Furthermore, a regular intake of quinoa, a grain originating from South America, as carbohydrate source in the diet, may bring additional health benefits attributed to its high nutritional value, characterized by presence of all essential amino acids, several minerals and vitamins, and essential omega-3 fatty acids, known as linoleic acid. Similarly to oats, consumption of 25 g serving of quinoa flakes after 4 weeks significantly decreased triacylglycerol levels in postmenopausal women [35]. Similar effects were observed after consumption quinoa biscuits, made with 60 g quinoa flour (per 100 g of product) after 4 weeks, improved lipid profile, characterized by decrease in total and LDL cholesterol levels as well as in triglycerides in healthy adults aged between 50 and 75 years old greater decreased: HDL ratio, weight and BMI, all of which may contribute to lowered CVD risk in older adults [58]. Interestingly, incorporation of 25 g portion of quinoa flakes eaten daily over period of 4 weeks helped to significantly reduce total cholesterol and LDL-cholesterol levels among overweight postmenopausal women, when compared to females who ate the equal portions of corn flakes. Further benefits for health included significantly lowered BMI and increased antioxidant activity demonstrated by higher glutathione levels in the overweight postmenopausal women [35].

Nuts and seeds

Increasing intake of nuts, in particularly almonds, walnuts, cashew, and peanuts, as sources of unsaturated fat, dietary fibers, vitamins and polyphenols, can provide various health benefits, linked to the improved metabolic health (decreased cholesterol levels and inflammation) and reduced incidences of chronic conditions linked with metabolic disturbances. For example, increasing nut and peanut butter consumption may help to lower risk of type 2 diabetes in women. Interestingly, even a single intake of large portion of 50 g of Brazil nuts may help to decrease the inflammatory markers long-term in apparently healthy adults with a mean age of 25 years [59], while eating portion of nuts five or more times per week compared with none, may reduce relative risk of developing diabetes by 27% in women [60]. Brazil nuts, being a rich source of antioxidants, in particularly selenium and vitamin E can help to lower the risk of prostate cancer among the men from Puerto Rico, Canada and the USA [61]. Interestingly, consumption of two Brazil nuts a day might be effective in increasing

selenium status as well as for increasing glutathione peroxidase, as the dose of dietary supplementation with 100 µg dose of selenomethionine [62], whereas a regular intake of Brazil nuts in diabetic patients have been shown to reduce oxidative DNA damage [63]. Interestingly, using nuts as replacement for carbohydrate snacks, after 3 months improved glycaemic control and lipid profile in patients with type 2 diabetes. Briefly, incorporating a 75 g portion of mixed nuts can reduce glycated hemoglobin HbA1C levels, as well as decreased LDL cholesterol levels compared to intake of 3 whole-wheat muffins (188 g/day), with similar protein content to the nuts, and equal carbohydrate-derived energy content as the monounsaturated fatty acid-derived energy content in the nuts [42]. Importantly, eating nuts or adding seeds to common foods, like bread or snack, may also limit the number of less healthy snacks eaten throughout the day, such as candy bars or cookies. For example, intake of bread added with flaxseeds (40 g a day) after 12 months significantly decreased BMI in apparently healthy women [64,65]. Supplementation with 30 g of roasted flaxseed powder for 3 months significantly reduced BMI in people with dyslipidemia [66]. Incorporation of 20 g portion of grounded flaxseed to daily diet of hypercholesterolemic patients after 60 days helped to reduce BMI [67]. Intake of 30 g of milled flaxseed after 12 weeks significantly reduced waist circumference in individuals with metabolic syndrome [68].

Chia seeds, harvested from plant *Salvia hispanica* L., are rich source of essential fatty acids, such as Alpha-Linoleic Acid (ALA), and dietary fibers, including both soluble and insoluble fibers. This nutritional composition of chia has been shown to benefit health of apparently healthy individuals, and depending on the dose of chia added, may help to lower postprandial blood glucose level and HDL cholesterol concentrations, as well as decrease diastolic blood pressure [69]. For example, regular Chia seed consumption may help to improve lipid profile, observed as reduced triglycerides and LDL cholesterol concentrations, as well as free fatty acids and saturated fatty acids. As chia is a rich source of plant-derived omega-3, it consumption can increase HDL cholesterol levels and improve polyunsaturated fatty acids status, including ALA, EPA, and LA concentrations [70]. Interestingly, adding a 40 g portion a day of chia seeds among adults with type 2 diabetes for 12 weeks significantly reduced systolic blood pressure compared to control [71]. Similarly, incorporation to the diet baked products made with chia flour (35 g a day) after 12 weeks significantly reduced both systolic and diastolic blood pressure in hypertensive individuals [72]. In addition, eating chia added breads (15 g/1000 kcal) after 4 weeks significantly decreased systolic blood pressure in type II diabetics [73].

Similar improvements in cardiometabolic health outcomes have been also observed in regular consumers of flaxseeds. Addition of portions ranging from 13 to 26 g of ground flaxseeds to the meals after 12 weeks significantly reduced glucose levels in overweight and obese individuals [74]. Consumption of whole flaxseed grain (40 g) alone or within the bread (40 g) after 12 weeks decreased glucose concentrations in obese and glucose intolerant individuals [75]. Similarly, supplementation with 40 g portion of grounded flaxseed after 8 weeks significantly reduced triacylglycerol levels and increased HDL cholesterol concentrations in individuals with dyslipidemia [76]. Also, in the same group addition of 30 g serving of roasted flaxseed powder, after 3 months led to similar significant decrease in triacylglycerol levels and increased HDL cholesterol [66]. Similarly, adding 20 g a day of grounded flaxseed to the diet reduced triacylglycerol in hypercholesterolemic individuals [67]. Addition of 30 g serving of milled flaxseed after 12 weeks significantly reduced triacylglycerol levels in individuals with metabolic syndrome [68]. Finally, adding a 30 g of roasted flaxseed powder after 3 months significantly reduced systolic and diastolic blood pressure in people with dyslipidemia [66].

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How to cite this article: Jurek JM. Implications of Plant Foods in Weight Management: Focus on Metabolic Health. 2022 Nov 30; 3(11): 1440-1450. doi: 10.37871/jbres1618, Article ID: JBRES1618, Available at: https://www.jelsciences.com/articles/jbres1618.pdf