Consumption of Plant Seeds and Cardiovascular Health
Epidemiological and Clinical Trial Evidence

Emilio Ros, MD, PhD; Frank B. Hu, MD, PhD

After decades of epidemiological and clinical research, the influence of overall diet on health and disease, particularly coronary heart disease (CHD), has become widely accepted. The pioneering ecological and metabolic studies of Keys and colleagues placed the focus on fat types, showing that populations consuming more saturated fatty acids (SFAs) had higher blood cholesterol levels and associated higher rates of CHD, whereas individuals fed SFAs had increased blood cholesterol levels, as well as individuals fed SFAs had increased blood cholesterol levels, as well as individuals fed SFAs had increased blood cholesterol levels, as well as individuals fed SFAs had increased blood cholesterol levels, as well as individuals fed SFAs had increased blood cholesterol levels, as well as individuals fed SFAs had increased blood cholesterol levels, as well as individuals fed SFAs had increased blood cholesterol levels, as well as individuals fed SFAs had increased blood cholesterol levels, as well as individuals fed SFAs had increased blood cholesterol levels, as well as individuals fed SFAs had increased blood cholesterol levels. The integral role of seeds in preagricultural diets is underappreciated given their high energy and nutrient density. Seeds are also particularly important in human nutrition because of their unique composition in bioactive compounds. Of note, in the past decade, a large body of scientific evidence has been built on the beneficial effects of increasing the consumption of plant seeds and derived products on various health outcomes, chiefly CVD, T2DM, and intermediate markers. The purpose of this review is to summarize the state of the evidence for the cardiovascular health effects of plant seeds, a food category bound to have a prominent place in health-promoting diets.

Data Sources and Selection of Studies on Plant Seeds and Cardiovascular Health

For this narrative review we conducted a comprehensive search of MEDLINE and EMBASE through December 2012 for English language descriptions of seed composition, reports of epidemiological and clinical studies describing the effects of seeds (whole grains, tree nuts and peanuts, pulses, cocoa and cocoa products such as chocolate, and coffee) on cardiometabolic outcomes, and the most recent reviews and meta-analyses of these studies. We also searched for reviews

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and meta-analyses of the effects of the main bioactive seed components on the same outcomes. Finally, we searched references cited in original studies and reviews identified, together with articles citing landmark clinical studies, reviews, and meta-analyses, as provided by the publishers of individual articles in their Websites. Data were examined for relevance, quality, and consistency and independently extracted by the 2 authors, who reached a consensus when in doubt about a specific citation. Given that, up to the time of submission, few controlled trials on the effects of seed consumption on clinical end points had been published, we have derived the core of scientific evidence from prospective cohort studies reporting disease outcomes and RCTs with intermediate end points, with a particular emphasis on meta-analyses of such studies.

**Broad Definition of Seeds and Their Purpose in Nature**

Seeds are small embryonic plants enclosed in a coat, the product of the ripened ovule of flowering plants after pollination and the completion of the process of reproduction. Seeds are made of complex matrices in the outer layer and the germ, rich in minerals, vitamins, and bioactive phytochemicals that protect the plant’s DNA from oxidative stress, thus facilitating the perpetuation of the species.\(^{28}\) On the other hand, the endosperm of seeds stores nutritive components to sustain the future seedling with a variable mixture of high-quality protein, complex carbohydrate, and fat depending on the type of seed. In this sense, seeds are like eggs, which also contain nutrients to sustain the growth of bird and reptile embryos. For instance, seeds contain sizable amounts of phytosterols, important structural components of plant membranes that stabilize phospholipid bilayers just as the cholesterol that abounds in eggs does in animal cell membranes.\(^{29}\) Whole seeds provide a wide array of bioactive molecules likely to have significant health benefits.

**Widely Consumed Seeds**

Edible seeds having a significant contribution to human nutrition include grains (cereals), nuts, legumes, and cocoa and coffee beans. Human populations derive most of their energy needs from seeds or seed products, particularly grains (wheat, corn, and rice) and legumes (soybeans). Seeds also provide most culinary oils and widely consumed beverages (coffee).

Grains (cereals) include wheat, oats, rye, rice, barley, millet, and corn.\(^{30}\) The foods originating from them range from highly nutrient-dense whole grain breads and cereal foods such as oats, to less nutrient-dense white rice, white bread, pasta and noodles or refined grain products with high levels of added sugar, fat, and sodium, such as many biscuits, pastries, and cakes.

Nuts are dry fruits with 1 seed in which the ovary wall becomes hard at maturity. The most popular edible tree nuts are almonds, walnuts, hazelnuts, and pistachios. Other common edible nuts are pine nuts, cashews, pecans, macadamias, and Brazil nuts.\(^{31}\) The consumer definition also includes peanuts, which botanically are legumes but are widely identified as part of the nuts food group. In addition, peanuts have a similar nutrient profile to tree nuts.\(^{32}\)

Pulses are the seeds of leguminous plants contained within pods. Lentils, chickpeas, black-eyed peas, and a variety of dry beans, including pinto, kidney, navy, and fava beans, are the most common edible pulses.\(^{33}\) The term pulses excludes legumes used for oil extraction, such as soybeans and peanuts, and those harvested green, such as green peas and green beans, which are classified as vegetables. Pulses usually require cooking before consumption and are eaten untransformed, unlike soybeans, which are the basis for soy oil and various foods such as tofu and derived products, widely consumed in Asia and by vegetarian populations worldwide.

Cocoa beans are the seeds of the tropical tree *Theobroma cacao*. The main product derived from cocoa is chocolate, a variable combination of cocoa solids, cocoa butter, milk, and sugar.\(^{34}\) The roasted, ground seeds of the *Coffee* plant are used to brew coffee, which competes with tea as the most consumed beverage worldwide.

Grains, nuts, legumes, and cocoa products represent a sizable contribution to human energy consumption in various populations, whereas daily coffee drinking is customary for many individuals worldwide. Many other edible seeds that are sparingly consumed and contribute only marginally to energy intake will not be dealt with here: pepper, mustard, cumin, capers and other seasoning seeds; flax, hemp, pumpkin, sesame, and sunflower seeds; berries; and others like coconut.

**Composition of Edible Seeds**

The macro- and micronutrients, minerals, vitamins, and phytochemicals in seeds reflect their role of nourishment and protection of the future seedling (Table 1 and Table 2). Edible seeds, particularly fat-rich nuts and cocoa products, are good sources of energy (Table 1). Brewed coffee is an exception because of the lack of macronutrients. The protein from seeds provides most essential amino acids, although some foods must be complemented to obtain significant amounts of all of them. For instance, the content of sulfur amino acids methionine and cysteine is marginal in most nuts\(^{38}\) and pulses,\(^{39}\) whereas grains contain sizable quantities,\(^{40}\) a reason why mixing the former with cereals suffices to meet human requirements. Again, with the exception of coffee, seeds are rich in carbohydrate and fiber (Table 1). Most energy in nuts comes from fat, but fatty acids are mostly unsaturated. Some nuts, especially walnuts, contain sizable amounts of PUFA, including linoleic acid (18:2n-6) and α-linolenic acid (C18:3n-3), the principal plant n-3 fatty acid.\(^{52}\) Conversely, SFAs abound in cocoa seeds, but the predominant species is stearic acid (C18:0), the consumption of which does not raise cholesterol as shorter-chain SFAs do.\(^{40}\)

Regarding micronutrients (Table 2), the folate content of seeds and seed products ranges from low to moderate, but frequent consumption is likely to contribute to adequate folate intake. The seed content of tocopherols (the main vitamin E compounds) is also low to moderate, with the exception of nuts, which can be particularly rich in α-tocopherol, the principal vitamin E species. Regarding minerals, seeds are excellent sources of potassium (K\(^{+}\)), magnesium (Mg\(^{2+}\)) (excluding coffee), and calcium (Ca\(^{2+}\)). Like all vegetables, unprocessed seeds have very low sodium content. Seeds contain enough phytosterols to build the cell membranes of the future.
Table 1. Average Nutrient Composition of Selected Seeds and Seed Products

<table>
<thead>
<tr>
<th>Seeds</th>
<th>Energy, kJ</th>
<th>Protein, g</th>
<th>Carbohydrate, g</th>
<th>Fiber, g</th>
<th>Total Fat, g</th>
<th>SFA, g</th>
<th>MUFA, g</th>
<th>PUFA, g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole grain flour</td>
<td>465–1587</td>
<td>2.6–15.9</td>
<td>23.0–76.9</td>
<td>1.8–23.8</td>
<td>0.9–6.5</td>
<td>0.2–1.1</td>
<td>0.2–2</td>
<td>0.3–2.6</td>
</tr>
<tr>
<td>Tree nuts and peanuts</td>
<td>2200–3000</td>
<td>7.8–23.7</td>
<td>12.3–32.7</td>
<td>3.0–12.2</td>
<td>46.0–76.1</td>
<td>3.7–11.9</td>
<td>8.9–59.3</td>
<td>1.5–47.2</td>
</tr>
<tr>
<td>Pulses (baked)</td>
<td>352–687</td>
<td>4.8–9.0</td>
<td>15.6–27.4</td>
<td>5.4–10.5</td>
<td>0.2–2.6</td>
<td>0.04–0.27</td>
<td>0.02–0.58</td>
<td>0.1–1.2</td>
</tr>
<tr>
<td>Dark chocolate</td>
<td>2286–2504</td>
<td>4.9–7.8</td>
<td>45.9–61.2</td>
<td>7.0–10.9</td>
<td>31.3–42.6</td>
<td>18.5–24.5</td>
<td>9.5–12.8</td>
<td>1.1–1.3</td>
</tr>
<tr>
<td>Coffee (per cup)*</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.05</td>
<td>0.005</td>
<td>0.036</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Data for raw products and 100-g serving size, except where specified. MUFA indicates monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; and SFA, saturated fatty acids.

*One cup is made from ≈5 g of ground coffee.

Data derived from US Department of Agriculture Nutrient Database.35

Review of Evidence on Edible Seeds and Their Products

Numerous epidemiological studies have examined the consumption of edible seeds in relation to risk of CVD, T2DM, or mortality, and meta-analyses summarize the observational evidence. Meta-analyses have also been published on the effects of these foods on blood cholesterol, glycemic control, blood pressure, or vascular function from small, usually short-term RCTs. Table 3 lists the latest meta-analyses and their main results.45–61

Whole Grains

Before the Industrial Revolution, all cereals were stone-milled and contained the entire constituents of the grain kernel.62 The advent of industrialized roller milling at the end of the 19th century significantly changed the nutritional quality of milled grain. In the 1970s Burkitt and Trowell63 pioneered the link between chronic disease and refined grain by observing that Africans who consumed large quantities of whole plant foods had a lower prevalence of chronic diseases than Western countries where grain products are highly processed. Whole grains comprise germ, bran, and endosperm. In contrast, refining removes both the germ and bran along with fiber, vitamins, minerals, phenolic compounds, and phytochemicals.30,64 The unique constellation of constituents is thought to confer the beneficial effects of whole grains on chronic disease risk via mechanisms shared by all seeds (see section on Mechanisms for Beneficial Effects of Seeds).

A meta-analysis by Mellen et al65 of 7 prospective cohorts found a 21% lower risk of CVD for greatest in comparison with lowest whole grain intake. A more recent meta-analysis of 45 prospective cohort studies45 showed that, compared with participants who rarely or never consumed whole grains, those reporting an average intake of 48 to 80 g/d (3–5 servings/d) had a 21% lower risk of CVD and a 26% lower risk of T2DM (Table 3). Based on data from 21 short-term RCTs, this meta-analysis also found that whole grain interventions...
Table 3. Effect of Seed Consumption on CVD Outcomes Based on Selected Meta-Analyses of Findings of Epidemiological Studies and Randomized Clinical Trials

<table>
<thead>
<tr>
<th>Author (Year), Reference</th>
<th>Type of Study</th>
<th>n (Population)</th>
<th>Follow-Up</th>
<th>Outcomes</th>
<th>Effect of Increased Seed Consumption*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole grains</td>
<td></td>
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<tr>
<td>Ye (2012)</td>
<td>Meta-analysis of 8 cohort studies</td>
<td>298,592 (Generally healthy, 6–14 y)</td>
<td>Incident CVD</td>
<td>RR=0.79 (0.74–0.85)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Meta-analysis of 6 cohort studies</td>
<td>288,319 (Generally healthy, 6–12 y)</td>
<td>Incident T2DM</td>
<td>RR=0.74 (0.69–0.80)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Meta-analysis of 21 RCTs</td>
<td>Not available (Healthy or patients with HC or hypertension, 4–16 wk)</td>
<td>Lipid profile</td>
<td>Δ Total cholesterol: −0.83 mmol/L (−1.24 to −0.42)</td>
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<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>Δ LDL-cholesterol: −0.72 mmol/L (−1.34 to −0.11)</td>
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<td></td>
<td>Glycemic control</td>
</tr>
<tr>
<td>de Munter (2007)</td>
<td>Meta-analysis of 6 cohort studies</td>
<td>286,125 (Generally healthy populations, 6–18 y)</td>
<td>Incident T2DM</td>
<td>21% (13%–29%) risk reduction for a 2-servings per day increment</td>
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<tr>
<td>Nuts</td>
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<tr>
<td>Kris-Etherton (2008)</td>
<td>Pooled analysis of 4 US prospective studies</td>
<td>135,604 (CVD-free men and women, 6–17 y)</td>
<td>Incident CHD</td>
<td>RR=0.65 (0.47–0.89)</td>
<td></td>
</tr>
<tr>
<td>Banel and Hu (2009)</td>
<td>Meta-analysis of 13 walnut RCTs</td>
<td>365 (Subjects with normal lipids or HC, 4–24 wk)</td>
<td>Lipid profile</td>
<td>Δ Total cholesterol: −0.27 mmol/L (−0.38 to −0.15)</td>
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</tr>
<tr>
<td>Sabaté (2010)</td>
<td>Pooled analysis of 27 nut RCTs</td>
<td>583 (Subjects with normal lipids or HC, 3–8 wk)</td>
<td>Lipid profile</td>
<td>Δ Total cholesterol: −0.28 mmol/L (−0.37 to −0.20)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Δ LDL-cholesterol: −0.26 mmol/L (−0.34 to −0.19)</td>
</tr>
<tr>
<td>Pulses</td>
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<tr>
<td>Bazzano (2011)</td>
<td>Meta-analysis of 10 RCTs</td>
<td>268 (Subjects with normal lipids or HC, 3–8 wk)</td>
<td>Lipid profile</td>
<td>Δ Total cholesterol: −0.31 mmol/L (−0.42 to −0.19)</td>
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<td></td>
<td>Δ LDL-cholesterol: −0.21 mmol/L (−0.30 to −0.12)</td>
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<td></td>
<td>Δ Triglycerides: −1.67 mmol/L (−3.63 to 0)</td>
</tr>
<tr>
<td>Sievenpiper (2009)</td>
<td>Meta-analysis of 11 RCTs of pulses alone</td>
<td>253 (Subjects with T2DM, normoglycemia or HC, 1–96 wk)</td>
<td>Glycemic control</td>
<td>(Results as SMD)†</td>
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<td>Fasting glucose: −0.82 (−1.36 to −0.27)</td>
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<td>Fasting insulin: −0.49 (−0.93 to −0.04)</td>
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<tr>
<td></td>
<td>Meta-analysis of 19 RCTs of pulses in low-GI diets</td>
<td>72 (Subjects with type 1 diabetes mellitus, T2DM or normoglycemia, 2–52 wk)</td>
<td>HbA1c</td>
<td>Δ: −0.28 (−0.42 to −0.14)</td>
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<tr>
<td></td>
<td>Meta-analysis of 11 RCTs of pulses in high-fiber diets</td>
<td>641 (Subjects with type 1 diabetes mellitus, T2DM or normoglycemia, 1.4–156 wk)</td>
<td>Fasting glucose</td>
<td>Δ: −0.32 (−0.49 to −0.15)</td>
<td></td>
</tr>
<tr>
<td>Chocolate</td>
<td></td>
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<tr>
<td>Buitrago-Lopez (2011)</td>
<td>Meta-analysis of 5 prospective studies</td>
<td>60,455 (CVD-free men and women (patients with previous CHD in 1 study), 8–16 y)</td>
<td>Incident CVD</td>
<td>RR=0.63 (0.44–0.90)</td>
<td></td>
</tr>
<tr>
<td>Larsson (2012)</td>
<td>Meta-analysis of 5 prospective studies</td>
<td>131,345 (CVD-free men and women (patients with previous CHD in 1 study), 8–16 y)</td>
<td>Stroke</td>
<td>RR=0.71 (0.52–0.98)</td>
<td></td>
</tr>
<tr>
<td>Tokede (2011)</td>
<td>Meta-analysis of 10 RCTs</td>
<td>320 (Healthy subjects or subjects with CVD risk factors, 2–12 wk)</td>
<td>Lipid profile</td>
<td>Δ Total cholesterol: −0.16 mmol/L (−0.30 to −0.02)</td>
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<tr>
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<td></td>
<td>Δ LDL-cholesterol: −0.15 mmol/L (−0.27 to −0.03)</td>
</tr>
</tbody>
</table>

(Continued)
<table>
<thead>
<tr>
<th>Author (Year), Reference</th>
<th>Type of Study</th>
<th>n</th>
<th>Population</th>
<th>Follow-Up</th>
<th>Outcomes</th>
<th>Effect of Increased Seed Consumption*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hooper (2012)55</td>
<td>Meta-analysis of 21 RCTs reporting lipid outcomes</td>
<td>290</td>
<td>Healthy subjects or subjects with CVD risk factors</td>
<td>2–26 wk</td>
<td>Lipid profile</td>
<td>Δ LDL-cholesterol: −0.07 mmol/L (−0.14 to −0.0)</td>
</tr>
<tr>
<td></td>
<td>Meta-analysis of 6 RCTs reporting glycemic control</td>
<td>91</td>
<td>Healthy subjects or subjects with CVD risk factors</td>
<td>2–26 wk</td>
<td>Glycemic control</td>
<td>Δ Insulin: −2.65 μU/mL (−4.65 to −0.65)</td>
</tr>
<tr>
<td></td>
<td>Meta-analysis of 22 RCTs reporting blood pressure</td>
<td>918</td>
<td>Healthy subjects or subjects with CVD risk factors</td>
<td>2–18 wk</td>
<td>Blood pressure</td>
<td>Δ DBP: −1.60 mmHg (−2.77 to −0.43)</td>
</tr>
<tr>
<td></td>
<td>Meta-analysis of 11 acute RCTs on postprandial FMD</td>
<td>373</td>
<td>Healthy subjects or subjects with CVD risk factors</td>
<td>90–150 min</td>
<td>FMD</td>
<td>Δ FMD: 3.19% (2.04–4.33)</td>
</tr>
<tr>
<td></td>
<td>Meta-analysis of 11 chronic RCTs reporting FMD</td>
<td>382</td>
<td>Healthy subjects or subjects with CVD risk factors</td>
<td>2–18 wk</td>
<td>FMD</td>
<td>Δ FMD: 1.34% (1.00–1.68)</td>
</tr>
<tr>
<td>Ried (2012)56</td>
<td>Meta-analysis of 20 RCTs</td>
<td>865</td>
<td>Healthy subjects or subjects with CVD risk factors</td>
<td>2–18 wk</td>
<td>Blood pressure</td>
<td>Δ SBP: −2.77 mmHg (−4.72 to −0.82)</td>
</tr>
<tr>
<td>Coffee</td>
<td>Wu (2009)57</td>
<td>Meta-analysis of 21 cohort studies</td>
<td>407,806</td>
<td>Generally healthy</td>
<td>4–32 y</td>
<td>Incident CHD</td>
</tr>
<tr>
<td></td>
<td>Larsson (2011)58</td>
<td>Meta-analysis of 11 cohort studies</td>
<td>479,689</td>
<td>Generally healthy</td>
<td>2–20.8 y</td>
<td>Incident stroke</td>
</tr>
<tr>
<td></td>
<td>Mostofsky (2012)59</td>
<td>Meta-analysis of 5 cohort studies</td>
<td>140,220</td>
<td>Generally healthy or patients with myocardial infarction</td>
<td>8–35 y</td>
<td>Incident congestive heart failure</td>
</tr>
<tr>
<td></td>
<td>Huxley (2009)60</td>
<td>Meta-analysis of 18 cohort studies</td>
<td>457,922</td>
<td>Generally healthy</td>
<td>2.6–20 y</td>
<td>Incident T2DM</td>
</tr>
<tr>
<td></td>
<td>Zhang (2011)61</td>
<td>Meta-analysis of 6 cohort studies</td>
<td>225,516</td>
<td>Generally healthy</td>
<td>8.4–12 y</td>
<td>Incident T2DM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>172,567</td>
<td>Generally healthy</td>
<td>6.4–33 y</td>
<td>Incident hypertension</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>Slightly elevated risk associated with light-to-moderate consumption of 1–3 cups/d (RR for comparison of 3 with 0 cups/d: 1.07 (0.97–1.20))</td>
</tr>
</tbody>
</table>

CHD indicates coronary heart disease; CI, 95% confidence interval; CVD, cardiovascular disease; DBP, diastolic blood pressure; FMD, flow-mediated dilatation; GI, glycemic index; HC, hypercholesterolemia; HOMA-IR, insulin resistance index; RCT, randomized, controlled trial; RR, relative risk; SBP, systolic blood pressure; SMD, standardized mean difference; and T2DM, type 2 diabetes mellitus.

*Risk ratios in meta-analyses of epidemiological studies, usually adjusted for multiple confounders, are for highest versus lowest categories of consumption or increased servings per day, as specified. Outcome changes (Δ) are means for average doses of seeds or seed products in seed diets in comparison with control diets in meta-analyses of RCTs; only statistically significant changes are shown. Values between parentheses are 95% confidence intervals.

SMDs are interpreted as follows: <0.4, small effect size; 0.4–0.7, moderate effect size; and >0.7, large effect size.
significantly reduced total and low-density lipoprotein (LDL)-cholesterol and fasting glucose. de Munter et al. conducted a meta-analysis of 6 prospective cohort studies and found a 21% reduction of T2DM risk for 2 servings/d increment in whole grain intake. The inverse association was stronger for bran than for germ, and there was no independent association for germ intake after adjustment for bran intake. These results provide some evidence to support the independent benefits of bran, although it is often difficult to tease out the effects of the individual components of a whole food.

**Nuts (Tree Nuts and Peanuts)**

Over the past 2 decades, 4 large prospective studies in the United States have reported on incident CHD in relation to frequency of nut consumption (including peanuts and peanut butter). As summarized in a pooled analysis, the results have consistently shown protection from CHD in participants who ate nuts at least twice per week in comparison with those who never or rarely consumed nuts (Table 3). Frequent nut consumption also relates inversely to total mortality, as suggested by recent reports from a large Dutch cohort and the Nurses’ Health Study. As reviewed, in the Physician’s Health Study, nut consumption was related to lower rates of sudden cardiac death, but not of stroke, heart failure, or atrial fibrillation; 2 other studies reported that nut and peanut intake was associated with a reduced risk of T2DM in women, but not in men.

More than 50 short-term RCTs have compared the effects of nut-enriched and nut-free diets on blood lipids and lipoproteins. A meta-analysis of 13 walnut-feeding studies and a recent pooled analysis of 25 RCTs using various nuts indicate a consistent cholesterol-lowering effect (Table 3). In the pooled analysis LDL-cholesterol was reduced by 7.4% for an average consumption of 67 g (2.4 oz) of nuts depending on nut dose and baseline LDL-cholesterol, and was similar by sex and age group and independent of the type of nut tested. Acute feeding studies indicate that nuts reduce postprandial glucose responses when consumed with foods having a high glycemic index, which suggests that they may be useful in diabetic control. Importantly, recent evidence from the PREvención con Dieta MEDiterránea (PREDIMED) intervention trial in Spanish subjects at high cardiovascular risk showed that a Mediterranean diet with 1 daily serving of mixed nuts reduced incident T2DM by 52% (95% confidence interval [CI], 4%-76%) after 4 years in comparison with a control diet. Limited evidence from RCTs suggests that nuts, particularly walnuts, have beneficial effects on blood pressure and endothelial function. Nut-feeding studies have also documented reduced circulating concentrations of inflammatory cytokines but no consistent changes of C-reactive protein. Finally, despite the high energy density of nuts, there is no evidence that their frequent consumption promotes obesity, probably because of a prominent satiating effect. In the PREDIMED trial, the Mediterranean diet supplemented with nuts significantly reduced the prevalence of metabolic syndrome in comparison with the control diet after a 1-year follow-up, mainly by reducing waist circumference.

Recently, the final results of the landmark PREDIMED RCT have been published showing for the first time a reduction of incident CVD after long-term consumption of a diet enriched in seeds. The PREDIMED study was a multicenter, nutrition intervention, primary prevention trial conducted in Spain wherein nearly 7500 participants at high cardiovascular risk, but with no cardiovascular disease at enrollment, were randomly assigned to 1 of 3 diets: a Mediterranean diet supplemented with daily doses of 30 g of mixed nuts (15 g walnuts, 7.5 g almonds, and 7.5 g hazelnuts), a Mediterranean diet supplemented with extravirgin olive oil (1 L/wk), or a control diet (advice to reduce dietary fat). After a median follow-up of 4.8 years, the participants in the 2 Mediterranean diet groups showed a 30% reduction in CVD events (myocardial infarction, stroke, or cardiovascular death) in comparison with the control diet. The nut diet was also associated with a significant 49% reduction in risk of stroke. Of note, the interventions were intended to improve the overall dietary pattern, but the major between-group differences in food intake were for the supplemental items. Thus, nuts were probably responsible for most of the observed benefits in the Mediterranean diet with nuts group. The results of the PREDIMED trial show the full potential of nuts and other healthy foods such as extravirgin olive oil to improve cardiovascular health.

**Pulses**

Two studies have examined the association between pulse consumption and risk of CVD. In the First National Health and Nutrition Examination Survey (NHANES) Epidemiological Follow-up Study, frequency of pulse plus peanut and peanut butter consumption was inversely associated with the incidence of CHD and CVD during a 19-year follow-up. Legume consumption ≥4/wk compared with <1/wk was associated with a 22% lower risk of CHD (adjusted risk ratio [RR] 0.78; 95% CI, 0.68–0.90) and an 11% lower risk of CVD (adjusted RR 0.89; 95% CI, 0.80–0.98). A case-control study conducted in Costa Rica, where dry beans are a staple, compared bean intake in 2119 survivors of a first acute myocardial infarction with matched population controls. In comparison with nonconsumers, 1 serving of beans per day was inversely associated with myocardial infarction, with an adjusted odds ratio of 0.62 (95% CI, 0.45–0.88). In another report on that study’s control population, substituting 1 serving of beans for 1 serving of white rice was associated with a 35% (95% CI, 15%–50%) lower risk of having the metabolic syndrome, related mainly to a decreased frequency of low high-density lipoprotein cholesterol and high fasting glucose. Similar findings were reported from NHANES 1999–2002; in comparison with nonconsumers, bean consumers had significantly lower body weight, smaller waist circumference, and lower systolic blood pressure. The risk of T2DM associated with pulse consumption has not been specifically assessed in epidemiological studies. However, pulses are an important component of dietary patterns clearly related to a lower T2DM risk, such as low–glycemic index, high-fiber, and Mediterranean diets.

Studies dating back to the 1980s showed that daily servings of pulses had a beneficial effect on the lipid profile. A recent updated meta-analysis of 10 RCTs evaluating the effects of pulse consumption on cholesterol levels indicates that a pulse-rich diet significantly decreases total cholesterol and LDL-cholesterol, with nonsignificant increases in
high-density lipoprotein cholesterol and reductions in triglycerides (Table 3).50 A meta-analysis on glucose metabolism indicates that pulses, alone or in low–glycemic index or high-fiber diets, modestly improve medium- to longer-term glycemic control in subjects with or without T2DM.51 Acute feeding studies indicate that pulses, like nuts, reduce postprandial glucose responses in comparison with high–glycemic index foods,59 further suggesting a beneficial impact on diabetic control.

**Cocoa and Chocolate**

Six recent cohort studies have reported on incident CVD in relation to the frequency of chocolate consumption (Table 3).52,53 Larsson et al53 reported lower stroke incidence associated with chocolate consumption and performed another meta-analysis that confirmed its protective effect. Two of the cohort studies included in the first meta-analysis on CVD outcomes52 also reported that blood pressure was significantly lower in the highest category of chocolate consumption.60,61 A prospective study evaluated the association between chocolate consumption and T2DM and reported a beneficial effect.62 A common problem is that different types of chocolate (dark versus milk versus white) were not distinguished in epidemiological studies. Even though the composition of chocolate is highly variable and diverges significantly from that of the original seed, it is the cocoa product most widely consumed.64 For this reason, most epidemiological studies analyzed consumption of any type of chocolate as an exposure variable.

A number of small RCTs assessing the short-term effects of dark chocolate or other cocoa products on serum lipids, blood pressure, or other intermediate markers of CVD have been published in the past decade (Table 3).54–56 Some used isolated flavanols, a subclass of flavonoid phenolics believed to be the principal bioactive component of cocoa.81 The effect sizes on lipids and blood pressure differ among meta-analyses, although the direction of the effects is consistently beneficial. These findings need to be confirmed in larger, longer, well-controlled feeding studies. On the other hand, a meta-analysis55 indicates a clear benefit of cocoa products on insulin resistance. Also, endothelial function was improved in both acute and chronic studies without evidence of heterogeneity between trials. Subgroup analyses indicated stronger benefit in participants at high risk of CVD than in healthy subjects for many outcomes.55 There is also RCT evidence that acute consumption of dark chocolate induces coronary vasodilation.84 Finally, studies support the additional antiatherogenic effects of cocoa products, such as reduction of oxidative stress,66–68 further suggesting a beneficial impact on diabetic control.

**Coffee**

Coffee has been extensively studied in relation to various diseases, including CVD and T2DM. In Wu et al’s meta-analysis of 21 prospective cohort studies on coffee and risk of CHD, there was no overall increased risk with greater consumption. Among women, but not men, there was an indication of an inverse association for moderate amount of coffee consumption (2–4 cups/d) and risk of CHD (Table 3). In a meta-analysis of coffee consumption and risk of stroke, in comparison with nonconsumers, consumption of 1 to 6 cups/d was inversely associated with risk of stroke, with the strongest association (17% lower risk) for 3 to 4 cups/d.58 Mostofsky et al69 conducted a meta-analysis of 5 prospective studies of coffee and heart failure and observed the lowest risk for consumption of 4 cups/d. These meta-analyses suggest a J-shaped relationship between coffee consumption and the incidence of CHD, stroke, and heart failure, with modest benefit associated with moderate consumption (3–4 cups/d).

In 2005, van Dam and Hu conducted a meta-analysis of 9 cohort studies of coffee consumption and risk of T2DM, including 193,473 participants and 8,394 incident cases. The RR of T2DM was 0.65 (95% CI, 0.54–0.78) for the highest (6 or 7 cups/d) and 0.72 (95% CI, 0.62–0.83) for the second highest (4–6 cups/d) category of coffee consumption in comparison with the lowest consumption category (0 or 2 cups/d).66 In 2009, Huxley et al60 updated the meta-analysis with 18 similar cohort studies. Overall, each additional cup of coffee per day was associated with a 7% reduction in the incidence of T2DM after adjustment for potential confounders. Risk reduction was 27% for consumers of 3 to 4 cups of total coffee per day and 36% for a similar consumption of decaffeinated coffee.

**Mechanisms for Beneficial Effects of Seeds**

The nutrient density in the complex matrices of seeds probably explains the lower CVD risk observed with higher seed consumption. Many of these food constituents synergistically
interact to beneficially affect various metabolic pathways intermediate in CVD and T2D risk. We will summarize, in brief, the scientific evidence on the bioactivity of known seed components to provide a mechanistic framework for their cardioprotective benefits.

**Fatty Acids**
Among seeds, nuts and chocolate have the highest total fat content (Table 1). However, with the exception of chocolate (rich in stearic acid), seeds have a low SFA content and most fat is made up of unsaturated fatty acids, with variable proportions of monounsaturated fatty acids and essential PUFAs, such as linoleic and α-linolenic acids, the latter being particularly abundant in walnuts. Although not investigated as much as marine n-3 fatty acids, in observational studies, higher exposure to α-linolenic acid has been associated with a moderately lower risk of CVD. It has been known for decades that SFA intake raises blood cholesterol, whereas replacing SFA with monounsaturated fatty acids or PUFA decreases blood cholesterol, with parallel effects on CVD risk. As mentioned, monounsaturated fatty acids or PUFA decreases blood cholesterol, whereas replacing SFA with very low amounts of macronutrients, whole seeds are important sources of protein. In large observational studies, increased consumption of plant protein as opposed to animal protein has been consistently associated with a moderate reduction in incident CHD. A mediating factor in protection from CVD by plant protein might be an inverse association with blood pressure. The Optimal Macronutrient Intake Trial to Prevent Heart Disease (OmniHeart) also demonstrated that partial substitution of carbohydrate with protein (about half from plant sources) lowered blood pressure and improved the lipid profile in prehypertensive and hypertensive subjects. Again, it is difficult to dissociate the benefit from the vegetable protein per se from the synergizing effects of other bioactive constituents in the protein-containing foods. Some amino acids in seeds may be particularly relevant to CVD protection, such as L-arginine, which is the substrate for endothelium-derived nitric oxide synthesis, a principal regulator of vascular tone and blood pressure. The L-arginine content of seeds probably contributes to the beneficial vasomotor effects of diets or meals rich in soluble β-glucans, whole grains contain little soluble fiber but are rich in insoluble fiber (bran), whereas the main sources of soluble fiber in the usual diet are fruit and vegetables. Observational studies have consistently shown that increased intake of dietary fiber, usually from cereals rather than from fruit and vegetables, is associated with reduced incidence of CVD and T2D. The reason for this apparent contradiction is that, in epidemiological studies, insoluble fiber cannot easily be dissociated from whole grain foods, which provide many other bioactive phytochemicals associated with beneficial health effects, as discussed here. Dietary fiber may also reduce CVD and T2DM risk through blood pressure reduction, improvement of insulin sensitivity, changes in secretion of various gut hormones that may act as satiety factors, and anti-inflammatory effects.

**Carbohydrate and Fiber**
With the exception of coffee as a beverage, which contains very low amounts of macronutrients, whole seeds are important sources of slow-release carbohydrate and dietary fiber, a nonabsorbable nutrient that has received much attention in nutritional epidemiology. There are 2 main types of dietary fiber: metabolically inert insoluble fiber and bioactive soluble or viscous (gel-forming) fiber, which has cholesterol-lowering properties and reduces postprandial glucose responses after carbohydrate-rich meals. With the exception of oat and barley, rich in soluble β-glucans, whole grains contain little soluble fiber but are rich in insoluble fiber (bran), whereas the main sources of soluble fiber in the usual diet are fruit and vegetables. Observational studies have consistently shown that increased intake of dietary fiber, usually from cereals rather than from fruit and vegetables, is associated with reduced incidence of CVD and T2D. The reason for this apparent contradiction is that, in epidemiological studies, insoluble fiber cannot easily be dissociated from whole grain foods, which provide many other bioactive phytochemicals associated with beneficial health effects, as discussed here. Dietary fiber may also reduce CVD and T2DM risk through blood pressure reduction, improvement of insulin sensitivity, changes in secretion of various gut hormones that may act as satiety factors, and anti-inflammatory effects.

**Figure.** The consumption of seeds improves cardiovascular health because of their unique composition in bioactive nutrients and phytochemicals and a complex synergy among them for effects on metabolic and vascular physiology pathways. The main known nutrients of seeds are represented together with their principal biological targets (long-arrow connections). The net effects on intermediate markers of cardiovascular risk that have been demonstrated for most seed classes in clinical trials are cholesterol-lowering, improved glycemic control, decreased blood pressure, improved vasomotion, reduced platelet aggregation, and antioxidant and anti-inflammatory actions. The overall result is reduced CVD and T2DM, as suggested for all seeds in observational cohort studies and observed for nuts in clinical trials. See text for details. Ca indicates calcium; carb, carbohydrate; CVD, cardiovascular disease; FMD, flow-mediated vasodilation; GI, glycemic index; K, potassium; Mg, magnesium; NO, nitrous oxide; and T2DM, type 2 diabetes mellitus.
enriched with nuts and cocoa products. For instance, in a clinical trial in hypercholesterolemic subjects, a diet containing walnuts (18% of the total energy) improved endothelial function in comparison with a Mediterranean diet, and it was estimated that walnut intake increased dietary l-arginine up to 1.4 g/d, which is close to supplement doses showing vaso-motor effects in clinical studies.

**Sterols**

Like all plant foods, seeds are cholesterol-free, but their fatty fraction contains sizeable amounts of chemically related non-cholesterol sterols known as plant sterols or phytosterols, nonnutritive components that play important structural roles in membranes. Relevant for human physiology, phytosterols interfere with cholesterol absorption in the intestinal lumen and thus possess cholesterol-lowering properties. Phytophysosters are established nonpharmacological agents that are useful adjuncts to a healthy diet for helping lower serum total and LDL-cholesterol, resulting in average reductions of 10% at the usually recommended doses of 2 g/d, an effect additive to that of statins. However, at doses up to 2 g/d, the effect of phytosterols is dose-related; doses as low as 400 mg/d, easily achieved with frequent intake of various seed products (Table 2), were shown to significantly influence cholesteroler metabolism and reduce LDL-cholesterol by an average 5% in moderately hypercholesterolemic individuals.

There is also consistent experimental evidence that phytosterols possess anti-inflammatory properties, although clinical studies have proven inconclusive.

**Minerals**

Seeds contain little sodium but are rich in K, Mg, and Ca. All 3 are critical in cellular metabolism and many physiological processes, of which blood pressure regulation has been most studied. Whereas high sodium (salt) intake is associated with significantly increased risk of stroke and total CVD, intake of nonsodium minerals generally has the opposite effect. A meta-analysis of prospective studies relating dietary Ca intake with risk of CVD showed nonsignificant reductions of 8% for incident CHD and 14% for incident stroke comparing the highest with the lowest level of dietary Ca intake. Two similar meta-analyses have shown a significant inverse association between dietary K intake and risk of stroke, with a decrease in risk of 21% for every 1.64 g/d or 11% for every 1.0 g/d increase in dietary K intake. The latter dose of K can be obtained from combining seed servings in the usual diet (Table 2). The association of dietary K with lower CHD risk, however, is only suggestive. Concerning dietary Mg intake, a meta-analysis of prospective studies by Larsson et al. shows a modest but significant inverse association with stroke risk, with an 8% reduction for an increment of 100 mg/d in intake. Hypertension is the main risk factor for cerebrovascular disease; thus, the stronger beneficial effect of reducing sodium and increasing nonsodium mineral intake from dietary sources on stroke risk than CHD risk is ascribable to reductions of blood pressure. Indeed, changes in dietary mineral intake like those derived from increased seed consumption are believed to be instrumental in the substantial blood pressure–lowering effect of the Dietary Approaches to Stop Hypertension (DASH) diet.

Regarding dietary minerals and T2DM, limited evidence from prospective studies suggests that Ca intake relates inversely to risk. Observational studies more strongly support an independent protective role of Mg intake against T2DM, with a dose–response effect translating into a 14% risk reduction for each 100 mg/d increment in Mg intake. This dose of Mg is easily obtained with feasible daily servings of seeds and seed products (Table 2). Dietary K could also play a preventive role against T2DM, as suggested by findings from the Nurses’ Health Study after a 6-year follow-up; to our knowledge, there have been no further studies examining this association. Increasing intake of nonsodium minerals influences the risk of T2DM through their critical participation in intracellular processes related to glucose homeostasis, such as a cofactor role for enzymes involved in glucose transport, enhanced insulin signaling, and modulation of glucose-induced insulin secretion, which all lead to increased insulin sensitivity. Besides blood pressure reduction, increased intake of K, Mg, and Ca in the DASH dietary pattern is also believed to underlie its effect of improving insulin sensitivity, an example of multipurpose nutrient synergy.

**Tocopherols**

Among seeds, nuts are particularly rich in vitamin E compounds, mainly α-tocopherol, a well-known antioxidant that, together with vitamin C, carotenoids, and selenium, contributes to the body’s defense against reactive oxygen species. α-Tocopherol, the biologically most active and most frequently studied form of vitamin E, is a lipid-soluble molecule transported in blood in lipoprotein fractions that acts as a peroxyl radical scavenger in lipid environments, preventing lipid peroxidation in lipoproteins and membranes. By reducing LDL oxidation or other mechanisms, vitamin E also displays anti-inflammatory properties, inhibits platelet aggregation, and enhances nitric oxide bioavailability. This helps explain the beneficial health effects of a lifelong high intake of vitamin E. Thus, a large meta-analysis of 15 cohort studies reported that vitamin E intake was associated with a reduced CHD risk, with RR=0.76 (95% CI, 0.63–0.89) for the top tertile in comparison with the bottom tertile of intake. However, large-scale RCTs have shown an unexpected lack of efficacy for different doses of supplemental vitamin E or other antioxidants against CVD. A likely reason for the discrepancy between prospective studies and RCTs is that the latter usually enrolled patients with previous CHD or at high risk of CVD; established atherosclerotic damage is unlikely to regress with antioxidant treatment. Likewise, there is no evidence from RCTs that vitamin E helps prevent or manage T2DM. Hence, the use of vitamin E or other antioxidant vitamin supplements for CVD prevention is discouraged, whereas the recommendation stands for a healthy diet, rich in food sources of antioxidant nutrients such as fruits and vegetables, including seeds.

**Polyphenols**

Phenolic compounds are strong antioxidants ubiquitous in plants. They are structurally diverse, belonging to several families such as benzoic acid derivatives, flavonoids,
proanthocyanidins, stilbenes, coumarins, lignans, and lignins. Several thousand molecules with structural features of polyphenols (one or more phenolic rings with a variable number of hydroxyl groups) have been isolated from higher plants, and nearly 500 have been identified in various plant-based foods and beverages. Seeds, particularly nuts, pulses, and cocoa products, are particularly rich in polyphenols (Table 2), but they are present mostly in the outer layers and many are heat-labile. Thus peeling or roasting nuts, decontamination of cereals, or dehulling of pulses results in sizeable losses, as do boiling, frying, and microwave heating.

Polyphenols are strong antioxidants, but evidence is increasing of their pleiotropic effects, ie, flavanols, a type of phenolic abundant in cocoa and black tea, increase the availability of nitric oxide, which may explain their favorable vascular effects. In an acute study in heart-transplant recipients, flavanol-rich chocolate induced coronary vasodilation and a decrease in platelet adhesion, concomitant with a reduction in measures of oxidative stress in comparison with a similar product devoid of flavanols. Some flavonoids have been shown to inhibit nuclear factor κB, a critical pro-inflammatory protein that enhances the expression of cytokines and cell adhesion molecules. However, the precise molecular mechanisms underlying these beneficial effects remain elusive.

Mounting evidence from prospective studies indicates that higher intake of polyphenol-rich foods in general and of flavonoid-rich foods in particular is associated with protection from CVD, although potential publication bias and marked heterogeneity in results across studies render the evidence inconclusive. The abundance of polyphenols in dark chocolate and coffee is thought to be responsible for the CVD benefit observed in regular consumers. A meta-analysis of 113 interventional studies of nearly 6000 subjects given different cocoa products or their pure phenolic extracts demonstrated improvement in various intermediate markers of cardiovascular health, including blood pressure, endothelial function, blood lipids, and insulin sensitivity. Several of the intervention studies reviewed were conducted with pure flavonoids and had effects similar to those elicited by the parent foods, which suggests that the benefit is due, at least in part, to these antioxidant molecules. However, no long-term RCTs have evaluated the effects of flavonoids or other phenolic compounds on clinical cardiovascular end points.

As shown in part in Figure, most bioactive seed components synergize to affect multiple metabolic and vascular physiology pathways leading to protection from CVD and T2DM. For the sake of simplicity, the scheme cannot include all the reported effects of particular seed molecules. For instance, besides their proven antioxidant, vascular, and antiplatelet effects, polyphenols have been shown to lower LDL-cholesterol and improve insulin sensitivity in RCTs. The complex bioactivity and multifunctionality of whole seed components supports their important role in a heart-healthy diet.

**Implications for Dietary Recommendations**

The current dietary strategies for CVD prevention focus primarily on the role of individual macronutrients (eg, fat, carbohydrates, or protein). Although reduction in the percentage of calories from dietary fat intake has been commonly recommended, long-term RCTs have provided no good evidence that reducing dietary fat per se can reduce CVD risk. Likewise, carbohydrate restriction alone is unlikely to have appreciable long-term impact on CVD. It is now recognized that overfocus on individual nutrients is counterproductive, because it misses the complexities of foods and overall eating patterns. A simpler and more friendly food-based dietary approach should be easier to communicate to the public and to implement in dietary practice. The past decade has seen an expansion of epidemiological and clinical research on the roles of seeds in the prevention of CVD, revolutionizing our thinking about the biological mechanisms that link dietary factors and CVD. Some foods that were thought unhealthy on the basis of fat content (eg, nuts) have become important in lowering serum cholesterol and controlling weight. The PREDIMED trial has convincingly demonstrated that a Mediterranean diet supplemented with nuts significantly reduces hard CVD end points. In addition, there is compelling evidence that increasing the consumption of whole grains and legumes confers cardioprotective benefits. Therefore, dietary recommendations should encourage substitution of whole grains and legumes for refined grains as part of a healthy diet. Whole grains, nuts, and legumes (but not dark chocolate or coffee owing to insufficient evidence at the time) were included in the American Heart Association report setting goals for health promotion and disease reduction for 2020. As reviewed here, current evidence suggests that moderate consumption of coffee and cocoa products can be incorporated into a healthy dietary pattern. The evidence base assembled in this review provides further support for the plant-based dietary patterns recommended by dietary guidelines.

**Conclusions**

There is substantial evidence that increased consumption of seeds, including whole grains, nuts, legumes, cocoa products, and coffee, is associated with lower risk of CVD and T2DM or a significant reduction in CVD risk factors such as serum cholesterol or blood pressure. Seeds are made of complex matrices in the outer layer and the germ, rich in minerals (K+, Mg2+, and Ca2+, but little sodium), vitamins (particularly tocopherols and folic acid), phytosterols, polyphenols, and other bioactive phytochemicals, where, among other functions, they serve to protect the plant’s DNA from oxidative stress and thus help perpetuate the species. On the other hand, the endosperm of seeds contains nutritive components to sustain the growth of the embryo, with a variable mixture of essential amino acids and fatty acids. Although some seed components (soluble fiber, unsaturated fatty acids, phytosterols) have the potential to reduce blood cholesterol, the whole seed provides a wide array of bioactive molecules likely to have synergistic effects on health outcomes. However, separating the effects of different components of seeds in epidemiological and clinical studies is exceedingly challenging. There is some evidence that a single component such as fiber may not be as beneficial when it is not consumed as a whole grain. Therefore, dietary recommendations should embrace a wide array of seeds as part of a plant-based dietary pattern, instead of putting too much emphasis on individual nutrients.
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