

## Review Article

# Health benefits of legumes and pulses with a focus on Australian sweet lupins

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**Background and Objectives:** The 68th United Nations General Assembly declared 2016 the International Year of Pulses. Therefore it is timely to review the current evidence of the benefits of legumes for human health with a focus on Australian sweet lupins. **Methods and Study Design:** Medline, Pubmed, Cochrane library were searched to identify cross-sectional/epidemiological studies, randomised controlled trials (RCTs) and systematic reviews. **Results:** The strongest evidence appears to be for links between eating legumes and reduced risk of colorectal cancer as well as eating soy foods and reduced LDL cholesterol. However, epidemiological studies and RCTs suggest that replacing several meat-based meals a week with legumes can have a positive impact on longevity, diabetes, cardiovascular disease and weight management, potentially via favourable effects on the gut microbiome. Sweet lupins are unique among legumes with one of the highest combined amounts of digestible plant protein (38%) and dietary fibre (30%). Unlike other legumes, their low amount of anti-nutritional factors negates the need for soaking/cooking and they can therefore be eaten uncooked. Sweet lupins may lower blood pressure, improve blood lipids and insulin sensitivity and favourably alter the gut microbiome. There is growing interest in pulses, especially sweet lupins, as ingredients to improve the nutritional value of baked goods (particularly gluten free) and to create novel products to replace meat. **Conclusion:** Legumes form part of most traditional diets. They, including sweet lupins, can play a useful role in health maintenance.

**Key Words:** pulses, legumes, sweet lupins, health, cardiovascular

## INTRODUCTION

The legume (or pulse) family (*Leguminosae*) consists of plants that produce a pod with seeds inside. In this article, the term “legumes” is used to describe the seeds of these plants. Common edible legumes include dry beans, broad beans, dry peas, chickpeas, lentils, soybeans, lupins, mung beans, lotus, sprouts, alfalfa, green beans and peas and peanuts. The terms “legumes” and “pulses” are used interchangeably because all pulses are considered legumes *but* not all legumes are considered pulses. The term “pulse”, as described in the Food and Agriculture Organization definition, is exclusively for crops harvested solely for the dry seed of leguminous plants.<sup>1</sup> This excludes legumes used for oil extraction (soybean, peanut) and those harvested green for food (green beans, peas and sprouts); the latter being classified as vegetables. Legumes are eaten in a variety of ways, including tofu (Japan, China), bean sprouts (China, Korea), chilli and refried kidney beans (Mexico), dhal and papadums (India), falafel and hummus (Middle East), navy bean soup (Mediterranean), tempeh (Indonesia), pea soup (Sweden), baked beans and peanut butter (US, Australia).

Legumes have been a staple food for many civilizations around the world for over 10,000 years. Their consumption dates back to as far as 5500 BC and they are thought to be one of the first crops cultivated by people.<sup>2</sup> They are valued around the globe as an inexpensive alternative to meat. Legumes are well adapted to adverse envi-

ronmental conditions and are highly resistant to disease and pests. They are widely grown in semi-arid regions while cereals require more water and intensive cultivation. Legumes are multi-purpose plants. Apart from being used as food for humans, they are also used as animal feed and are valued by farmers because of their ability to fix atmospheric nitrogen and increase the overall fertility of soil, reducing the need for expensive nitrogenous fertilisers. One of the early Greek botanists from the third century BC, Theophrastus, wrote of leguminous plants “reinvigorating” and “manuring” the soil. The Romans also used leguminous plants for green manuring and introduced the systematic use of crop rotations, a practice that was forgotten for a time during the early Middle ages.<sup>3</sup> The legume lupin is a seed of the domesticated *Lupinus* species of the genus *Lupinus*, belonging to the *Fabaceae* family of legumes. They have been consumed from at least ancient Egyptian, Roman and Incan times as a snack food around the Mediterranean and in the Americas, usually pickled to reduce the bitterness. *Lupinus angusti-*

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*folius* is the dominant variety of lupins grown in Australia, and often referred to as Australian sweet lupin or narrow-leaved lupin. Sweet lupins are devoid or have minimal amounts of the bitter alkaloids found in many traditional crops, and which have necessitated soaking in brine before consumption to avoid toxicity. They are currently used in crop rotation cycles as a nitrogen fixing crop, with the harvest being predominantly exported and, until recently, used for stock-feed. Australia currently produces close to 80% of the world's lupin crop. In recent years promising research demonstrating potential health benefits of lupin for humans has led to an increase in the utilization of lupin in human foods. Lupin flour has been used as an ingredient in cooking in regional areas of Australia in baked goods for many decades, with the food industry only recently recognising its potential to improve the nutritional composition of foods.

Legumes have been considered to be an economical dietary source of protein and are higher in protein (especially lupins) than most other plant foods. However new gut (ileal) absorption methodology, that assesses protein quality, has recently down-graded the value of leguminous protein over previous estimates.<sup>4</sup> Nevertheless they are still considered to be high in nutrients and phytochemicals, making them an important, inexpensive food staple in many developing countries. Supplementing diets based on cereals, roots and tubers with legumes is suggested as one of the best solutions to malnutrition in these countries. This reflects the potential role of legumes in improving the nutritional status of undernourished individuals.<sup>5,6</sup> In developed countries legumes can also play an important role by adding biodiversity to the diet.

Evidence is strengthening for the role legume consumption can play in disease protection, as are calls to emphasise plant foods in order to reduce the environmental impacts of diets high in animal foods.<sup>7,8</sup> Legumes have been regarded in affluent societies as food for poor people, but emerging research has encouraged their use as a "health food" for affluent people.<sup>3</sup> This 'healthy' reputation has recently been challenged by advocates of low carbohydrate and paleo diets. Should legumes be avoided, or can they play a part in a healthy diet? This paper looks at the evidence for legumes, especially lupins, in a nutritious diet.

## CONSUMPTION OF LEGUMES AND RECOMMENDED INTAKE

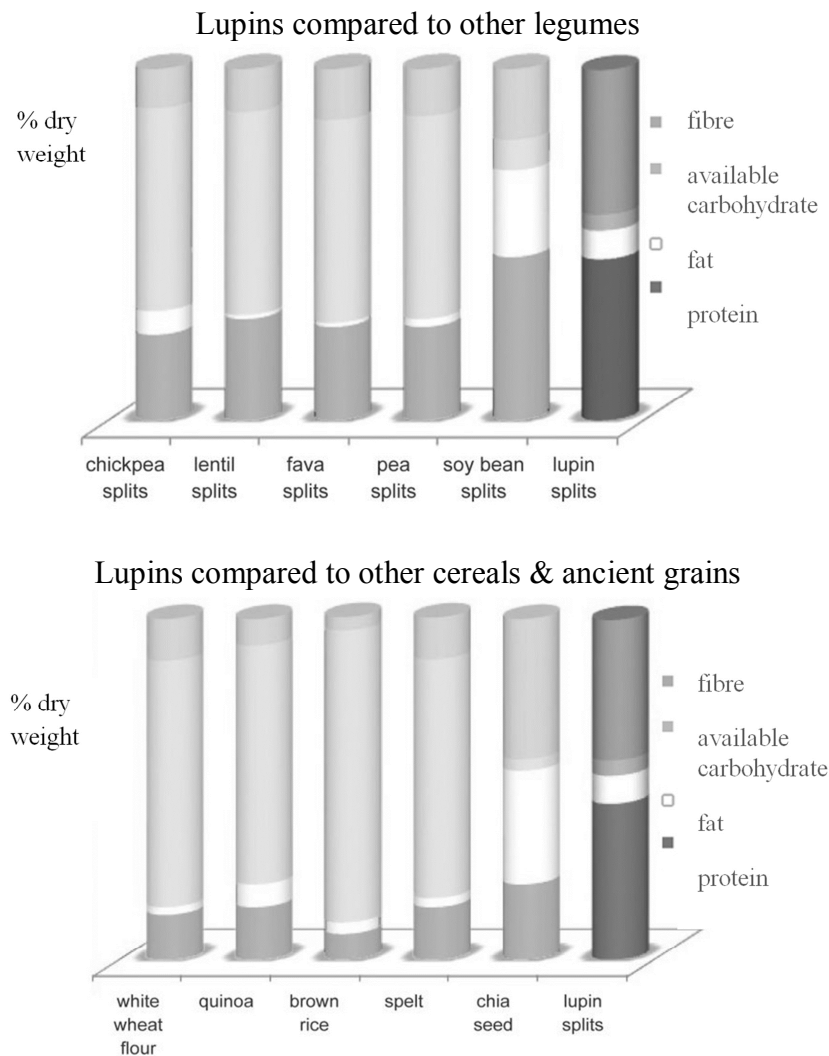
Legume intake is low in Australia. In 1995 the mean intake was less than 10 g a day for adults.<sup>9</sup> According to the 2007 National Children's Nutrition and Physical Activity Survey, Australian children aged 2-16 are eating only 4-

12 g legumes a day.<sup>10</sup> In 2011, the Australian Grains & Legumes Nutrition Council<sup>TM</sup> commissioned a survey to track consumption of legumes in Australia and found that Australians eat on average less than one third of a serve of legumes per week and only 22% eat legumes regularly.<sup>11</sup> In Europe, individuals living in Mediterranean countries consume between 8-23 g per capita daily while in Northern Europe the daily consumption is less than 5 g per capita.<sup>7</sup>

Consumption of legumes is recommended in the Australian dietary guidelines - recognising their favourable nutrient profile "Legumes provide a valuable and cost effective source of protein, iron, some essential fatty acids, soluble and insoluble fibre and micronutrients". The value of legumes as a nutritious food is reflected in their inclusion in both the 'meat and alternatives' food group as well as the vegetables food group. In a 2013 review of the Australian Dietary Guidelines, a number of changes have been made to the recommendations for the intake of legumes due to emerging research of their health benefits. The review of the evidence that informed the dietary guidelines found that recent studies confirm the protective effects of legumes. The strongest evidence is for links between eating legumes and reduced risk of colorectal cancer as well as eating soy foods and reduced LDL cholesterol.<sup>12</sup> The serving size has increased from ½ cup (75 g) to 1 cup (150 g) when legumes are eaten as a meat alternative (e.g. cooked dried or canned beans, chickpeas or lentils) and tofu is listed for the first time as a meat alternative with a serving size of 170 g. When legumes are eaten as a vegetable the serving size has remained the same at ½ cup (75 g) (e.g. cooked dried or canned beans, chickpeas or lentils, peas). The revised Australian Dietary Guidelines do not mention sprouted legumes but they would probably be classified under "vegetable" (see Table 1). The Australian dietary guidelines do not provide guidance on the number of serves per week for legumes. The Grains & Legumes Council<sup>TM</sup> recommends eating legumes 2-3 times a week to reduce risk of heart disease and help manage blood glucose levels.<sup>11</sup> The guidelines also encourage variety through increasing intake of alternatives to meat, including legumes and tofu. Legumes are now also recommended in the vegetable group for inclusion in diets of infants and toddlers from 6 months of age. To meet the new recommendations for legumes in the revised Australian Dietary Guidelines, adults will need to increase their intake by 470%.<sup>12</sup> The top three reasons reported for not eating legumes were; lack of knowledge of how to prepare them, a poor understanding of the health benefits and concern over side effects such as bloating and flatulence.<sup>11</sup>

**Table 1.** What is a serve of legumes? Changes to the Australian Dietary Guidelines

Food group	Previous Australian Dietary Guidelines (1998)	Current Australian Dietary Guidelines (2013)
Vegetables	75 g (1/2 cup) cooked dried beans, peas or lentils	- 75 g (1/2) cooked dried or canned beans, chickpeas or lentils, no added salt - sprouted legumes
Meat and alternatives	75 g (1/2 cup) cooked dried beans, lentils, chickpeas, split peas or canned beans	- 150 g (1 cup) cooked dried beans, lentils, chickpeas, split peas or canned beans - 170 g tofu



**Figure 1.** Macronutrient and dietary fibre composition of lupins compared to other legumes and grains. Source: Copyright Lupin Foods Australia, reprinted with permission. [www.lupinfoods.com.au](http://www.lupinfoods.com.au).

## NUTRITIONAL PROFILE

### *Legumes are uniquely rich in both protein and dietary fibre*

Legumes provide a range of essential nutrients including protein, low glycaemic index carbohydrates, dietary fibre, minerals and vitamins. Legumes are uniquely rich in both protein (17%-20% dry weight in peas and beans, 38%-40% in soybeans and lupins) and dietary fibre (5%-37% dry weight).<sup>4,13</sup> This contrasts with the protein content of cereals which is about 7%-13%. In fact, sweet lupins have one of the highest combinations of both protein (38% dry weight in lupin splits) and fibre (30% dry weight + 5% inulin in lupin splits) of all the pulses and of all plant foods. Lupin also contains low amounts of carbohydrate (6-10%) compared to other legumes (35%-50%) and grains (65%) (see Figure 1 and Table 2).<sup>14</sup>

Legumes are the only cultivated plant that has the ability fix nitrogen from the atmosphere through the action of special bacteria that live in nodules on their roots. This is why legumes are among a better plant-based source of dietary protein. They are higher in protein than most other plant foods and have twice the dietary protein content of cereal grains. This nitrogen is used by the plant to make protein which becomes available to humans when the seeds are eaten. The nitrogen is returned to the soil when

the legume plant dies. This process helps to improve soil fertility which in turn helps other plants grow. Historically, this “green manuring” was important for the nutrient-poor Mediterranean soil.<sup>6</sup>

However, legumes are considered to be incomplete proteins (except soy) because they contain relatively low quantities of the essential sulphur containing amino acids methionine, cystine and cysteine (which are found in higher amounts in grains). Grains, on the other hand, contain relatively low quantities of the essential amino acid lysine, which legumes contain.<sup>4,13</sup> This is why diets that exclude animal foods need to contain a variety of plant foods to ensure an adequate intake of essential amino acids.

Legumes are particularly rich in low glycaemic index carbohydrates, resistant starch (RS), oligosaccharides (OS, mainly raffinose) and fibre.<sup>15</sup> The RS, OS and fibre pass undigested through the stomach and small intestine until they reach the colon, where they act as “prebiotics” or “food” for the “probiotic” or beneficial bacteria residing there. Their bacterial fermentation leads to the formation of short-chain fatty acids, such as butyrate, which may improve colon health by promoting a healthier gut microbiome reducing the risk of colon cancer.<sup>16</sup> They are also satiating which may help reduce food intake thus playing

a potential role in weight management.<sup>17,18</sup> Additionally, they can help moderate blood sugar levels after meals and improve insulin sensitivity.<sup>19-22</sup>

#### **Legumes have a favourable micronutrient profile**

Legumes are nutrient dense with low energy density. Legumes are a good source of B vitamins, iron, zinc, calcium, magnesium, selenium, phosphorus, copper and potassium, but are a poor source of fat soluble vitamins and vitamin C. They are generally low in fat and have no cholesterol (being an animal sterol). (see Figure 1) Soybeans and peanuts are the exception, with significant levels of mostly mono- and polyunsaturated fatty acids, including alpha-linolenic acid.<sup>6</sup> They are a good source of linoleic (21%-53%) and alpha-linolenic acid (4%-22%).<sup>2,5</sup> Chickpeas have the highest monounsaturated fatty acid content (34 g/100 g), butter beans have the highest saturated fat content (28.7 g/100 g) and kidney beans the highest polyunsaturated fat content (71.1 g/100 g). Lupins contain a higher monounsaturated fat and a lower saturated fat content.<sup>5</sup>

#### **Legumes contain phytonutrients and anti-nutritional factors**

The nutritional quality of legumes may be affected by anti-nutritional factors which they contain. These are phytochemicals that reduce the digestion and absorption of nutrients or interfere with their action. Some can also be toxic. Anti-nutritional factors can decrease palatability, diminish protein digestibility and mineral bioavailability.<sup>24</sup> Therefore legumes (except sweet lupin) should not be eaten raw. Traditional food preparation techniques

such as soaking, boiling, sprouting and fermenting not only improve flavour and palatability of legumes but also increase the bioavailability of nutrients, by deactivating anti-nutritional factors.<sup>25</sup>

The bioactive phytochemicals in legumes include: enzyme inhibitors, lectins, phytoestrogens, oligosaccharides, phytosterols, saponins, phytates, phenolic acids and flavanoids. The proteinaceous anti-nutritional factors include lectins, protease (trypsin, chymotrypsin) and amylase inhibitors and lipoxigenase. Non-proteinaceous compounds include phytic acid,  $\alpha$ -galactosides, phenolics, tannins, saponins, cyanogens and toxic amino acids.<sup>4</sup> However, some may play a role in the healthprotective characteristics of legumes for cardiovascular disease, diabetes and cancer and include phytosterols, isoflavones, lignans, saponins and alkaloids, as well as some bioactive sugars, oligosaccharides and phytates.<sup>23,24,26</sup> For example the polyphenolics in coloured seed coat types in particular, have antioxidant and anticarcinogenic activity. The concentration of simple polyphenols ranges from 321-2404 ug/100g fresh weight in green split peas and big lentils, and decreases in the following order: lentils > chickpeas > pinto beans > sweet lupins > white beans.<sup>5</sup>

Legumes contain several phenolic compounds (in addition to glutathione and tocopherols) which may protect against some cancers.<sup>27</sup> Isoflavonoids, a subclass of polyphenols, act as phytoestrogens. Isoflavones include genistein, daidzein, coumestrol, formononetin and biochanin A. Genistein, daidzein and biochanin A can act as oestrogen-related receptor  $\alpha$  agonists. Soybeans are rich in isoflavones (610-2440 ug/g), lentils are low (0.23-0.4 ug/g) where as soy sprout is high (coumestrol). Chickpeas

**Table 2.** Nutritional profile of selected legumes compared to wheat

	100 g raw lentils (red) <sup>†</sup>	100 g raw peas <sup>†</sup>	100 g raw mung bean sprouts <sup>†</sup>	100 g raw soy beans <sup>†</sup>	100 g Lupin flakes <sup>‡</sup>	100 g lupin flour <sup>§</sup>	100 g wholemeal flour <sup>†</sup>
Energy (kJ)	1198	300	84	1665	1350	1391	1471
Protein (g)	24	6	3	31	37	37	11
Fibre (g)	14	6	2	20	33	33	11
Carbohydrate (g)	35	8	1	13	6	11	65
Fat (g)	2.0	0.4	0.1	20	7.7	7.9	2.1
Saturated (g)	0.3	0.0	0.0	2.9	1.6	1.5	0.3
Polyunsaturated (g)	1.0	0.3	0.0	12.5	3.5	3.8	1.0
Omega 3 linolenic (g)	0.0	0.0	0.0	1.4	0.4	0.5	0.0
Monounsaturated (g)	0.3	0.1	0.0	3.0	2.6	2.6	0.8
Iron (mg)	7.5	1.8	0.3	9.5	4.0	4.9	3.0
Calcium (mg)	73	30	9	180	81	84	30
Zinc (mg)	3.0	1.0	0.5	4.0	3.5	3.6	1.3
Magnesium (mg)	82	32	12	230	188	189	103
Potassium (mg)	840	264	129	1800	715	810	317
Vit B-1 (mg)	0.40	0.32	0.03	0.76	0.64	3.00	0.40
Vit B-2 (mg)	0.16	0.14	0.10	0.16	0.02	1.00	0.10
Vit B-3 (mg)	2.3	2.3	0.4	2.7	2.2	1.90	5.5
(Niacin equivalents)	(5.3)	(3.4)	(0.99)	(10.7)	-	-	(7.6)
Folate equivalents (ug)	111	56	25	375	-	-	47
Vit B-6 (mg)	0.6	0.2	0.2	0.4	0.1	0.1	0.4
Vit C (mg)	3	33	10	0	0	0	0

Source:

<sup>†</sup>NUTTAB 2010 Food Standards Australia New Zealand. <http://www.foodstandards.gov.au/science/monitoringnutrients/nutrientables/nuttab/Pages/default.aspx>.

<sup>‡</sup>Food Standards Australia New Zealand. Australian Sweet Lupin. FSANZ May 2015. <https://www.foodstandards.gov.au/science/monitoringnutrients/nutrientables/Documents/Industry%20Report%20-%20Australian%20Sweet%20Lupin.pdf>.

<sup>§</sup>Irwin Valley Lupin Flour. [http://www.irwinvalley.com.au/?page\\_id=52](http://www.irwinvalley.com.au/?page_id=52).

contain 0.04 mg/100 g daidzein, 0.06 mg/100 g genistein, 0.14 mg/100 g formononetin and 1.7 mg/100 g biochanin A. Soybeans have high levels of daidzein (47 mg/100 g) and genistein (74 mg/100 g) but contain less formononetin and biochanin A compared to chickpeas (0.03 and 0.07 mg/100 g, respectively). Biochanin A and formononetin (high in chickpeas) can stimulate peroxisome proliferator-activated receptors (PPAR  $\alpha$  and  $\gamma$ ) which help to correct dyslipidaemia and restore glycaemia balance.<sup>5</sup> Research over the last 20 years has linked soy foods and/or phytoestrogens to a reduced risk of certain cancers including breast and prostate cancer, heart disease, osteoporosis and problems associated with menopause.<sup>2, 28, 29</sup>

Saponins are plant glycosides in which the non-sugar moiety is a steroid or a triterpenoid compound. Saponins are gastric irritants but may also exhibit hypocholesterolaemic and anticarcinogenic activity.<sup>5</sup> Saponins are found in lentils, chickpeas, soy, various beans and peas. Soy beans are particularly high in saponins even after extensive baking and processing.

Phytosterols are structurally similar to mammalian cholesterol, with 50%-85% being  $\beta$ -sitosterol. These can block the absorption of cholesterol from food. Black-eyed beans have only 13.5 mg/100 g fresh weight but sweet lupins (53.6 mg/100 g) and chickpeas (38.5 mg/100 g) are high in  $\beta$ -sitosterol.<sup>5</sup>

Phytic acid (inositol hexaphosphate) is found in all edible plant seeds, including legumes. Phytates chelate minerals (especially calcium and zinc) to form poorly soluble compounds that are not readily absorbed from the intestine, thus interfering with the bioavailability of these essential minerals.<sup>30</sup> Phytates can increase the risk of mineral deficiencies over time if animal food intake is low. Phytates do not appear to affect absorption of minerals from meat.<sup>31</sup> Phytates are a concern in developing countries where diets are often based on grains and legumes and in vegetarian, especially vegan, diets.<sup>32</sup> However dehulling, soaking, boiling/steaming, germination/sprouting, roasting, sun drying and fermentation of legumes activates an enzyme (phytase) which helps their breakdown.<sup>4, 30, 33</sup> Total removal of phytates is not desirable as some studies suggest they may help reduce the risk of developing bowel cancer.<sup>34</sup> They are a source of inositol which may also play a role in the reduction of the complications of diabetes.

Different types of lectins are found in legumes, where they may constitute up to 10% of the total protein content.<sup>35</sup> Lectins bind to carbohydrates and resist digestion and some can adversely affect the endothelial cells of the intestinal tract interfering with the absorption of nutrients. The lectin phytohemagglutinin is found in many types of beans, especially red kidney beans, and can be toxic if beans are improperly cooked or consumed raw.<sup>36</sup> Other lectins are not found in high enough concentrations in legumes to cause symptoms in humans. As a general rule, beans should never be eaten unless fully cooked and prepared. Soaking overnight and boiling at 212°F (100°C) for at least 10 minutes, degrades phytohemagglutinin and other legume lectins.<sup>36</sup> Sweet lupin seeds and sweet lupin flour are naturally low in lectins and saponins reducing the need for soaking or extended cooking and can there-

fore be eaten uncooked.<sup>37</sup>

Legumes are significant sources of resistant starch, which are fermented by colonic bacteria to short chain fatty acids. These fatty acids act locally within the gut improving colonic health and reducing the risk of bowel cancer.<sup>16, 38</sup> They are also absorbed into the portal circulation where they favourably affect glucose and lipid metabolism in the liver.<sup>38</sup> Galacto-oligosaccharides (GOS) are found in most legumes and can exert beneficial prebiotic effects in the large intestine but can also cause flatulence.<sup>5, 23</sup>

### Australian sweet lupin (*Lupinus angustifolius*)

The lupin seed has a dicotyledon structure, with a thick seed coat and the enclosed kernel. These kernels can be separated from their outer seed coat and milled to produce lupin flour and flakes. Protein and fibre fractions can also be isolated from the lupin seed. The protein content of lupin is high, approximately 38% of its weight in lupin splits. Over 85% of its storage proteins are 7S and 11S and the remaining 15% albumins. Lupin is a good source of arginine (3.6 g/100 g) but contains lower levels of sulphur-containing amino acids such as cysteine (0.4 g/100 g).<sup>39</sup>

The dietary fibre content of lupin kernels is about 30%. Lupin cell walls contain mostly insoluble fibre (86%), 1% soluble fibre and 8% oligosaccharides. It is however important to know that the chemical properties of this insoluble fibre have been described as being most similar to those of pectin and not to other insoluble non-starch polysaccharides.<sup>40, 41</sup>

Lupin contains approximately 6-7% fat with 81% being unsaturated and 19% being saturated fatty acids, with the majority of the fat being found in the form of triglycerides. The key fatty acids found in lupin kernel oil are oleic acid (28%) and linoleic acid (47%). It also contains the beneficial omega 3  $\alpha$ -linolenic acid (8%). The ratio of omega 3:omega 6 fatty acids (1:3.7) in lupin kernels is also favourable.<sup>42</sup> In addition to the key macronutrients, sweet lupin also contains a considerable number of beneficial phytochemicals. They have a high carotenoid content, composed of 134  $\mu$ g/g zeaxanthin and 50.43  $\mu$ g/g  $\beta$ -carotene, giving lupin flour its yellow colour and it also contains varying levels of phenolic compounds, such as catechins and rutin. Sweet lupin have negligible amounts of phytoestrogens.<sup>40, 43</sup>

Sweet lupin have very low levels of proteinaceous anti-nutrient phytochemicals such as alkaloids, saponins, lectins and phytates compared to its bitter cousins and other legumes. It contains negligible amounts of trypsin and chymotrypsin inhibitors (<0.1 mg/kg) known to interfere with digestion often found in other legumes.<sup>39</sup> Therefore, unlike most legume grains, sweet lupins do not require heating or chemical treatment to denature the anti-nutritional factors so they can be eaten uncooked. Also, lectin activity is virtually non-existent in Australian sweet lupin.<sup>39</sup>

High levels of bitter-tasting alkaloids are found in older varieties of lupins. These alkaloids are highly toxic and offer the plants some protection against insect attack and fungal diseases, as well as stress tolerance. Bitter lupin seeds were used as human food after they had been care-

fully soaked in brine overnight and boiled. The majority of the alkaloids leached into the water, which was discarded. This method of preparation has been practiced since antiquity. The residual alkaloids left after soaking give the seeds a 'tangy' taste.<sup>41</sup> However, in the last 80 years lupins have been subjected to scientific breeding. One result of this effort was the discovery of genes that significantly reduce the alkaloid content of the plants and seeds. These genetically 'sweet' varieties (which includes sweet varieties of *L. albus* and *L. angustifolius*) can be eaten without soaking/cooking and without the risk of poisoning. In fact all sweet lupin now sold for human consumption must have low alkaloid levels of <200 mg/kg according to Australian Food Standards (see Table 2). In contrast the bitter varieties are 10 thousand times higher in alkaloids (15,000–22,000 mg/kg).<sup>41,44</sup> It is not clear if the newer sweet lupin varieties have lower levels of nutrients and phytonutrients than the older bitter varieties. Sweet lupins are also low in phytates and saponins (55 to 730 mg/kg) compared to many other legume species.<sup>5</sup> Due to the low levels of antinutritional factors in sweet lupins, they do not require heat or chemical treatment, thus rendering them nutritionally superior to other legumes.

As lupin is a high protein food, and in the legume family alongside peanuts and soy, it is important to note that it may act as a possible allergen in some individuals. A recent European study reported that in a large group of patients evaluated for food allergies, 1.6% showed positive skin prick sensitisation tests for lupin and out of these individuals about one third were diagnosed with a probable lupin allergy, with reactions varying from mild to severe. Lupin allergy can occur in individuals without existing food allergies or atopic conditions but is more frequently seen with cross-reactivity in those individuals with allergies to peanuts and other legumes, therefore individuals with a history of food allergies should be particularly cautious with, or avoid lupin.<sup>45</sup>

## LEGUMES, LONGEVITY AND CHRONIC DISEASES

Humans have observed, over many centuries, that diets low in meat and high in cereals and legumes, are beneficial for health. Epidemiological studies over the last 20 years have confirmed these observations i.e. that eating legumes can extend life by preventing chronic disease, including cardiovascular disease, diabetes, cancer and overweight, as well as improving gut health.<sup>7,13</sup> The mechanisms by which legumes provide this protective effect include their low saturated fat content and their low glycaemic index/high dietary fibre content which attenuates insulin responses and reduces hunger.

### Longevity

Legumes have been an important part of the diets of many long-lived food cultures such as the Japanese, who regularly eat soy foods such as tofu, natto and miso, and people from the Mediterranean where lentils, chickpeas and white beans feature.<sup>46</sup> The Food Habits in Later Life (FHILL) was a cross-cultural study conducted under the auspices of the International Union of Nutritional Sciences (IUNS) and the World Health Organisation (WHO),

coordinated by Wahlqvist and Kouris-Blazos. This study examined whether adherence to a Mediterranean-style diet pattern high in plant foods (including legumes) and low in animal foods predicted survival amongst long-lived cultures. A total of 818 participants aged 70 years and over, were recruited from five IUNS centres: Japan (n=89), Sweden (n=217), Greece (rural areas n=182) and Australia (Greek-born n=189 and Anglo-Celtic Australians n=141). Between 1989–1991 cross-sectional data were collected using validated questionnaires, along with blood tests and anthropometry. Mortality data were collected after 5 to 7 years.<sup>47</sup> A Mediterranean Diet Pattern Score (MDPS) ranging from 0–8 was developed by Trichopoulou, Kouris-Blazos and Wahlqvist and was applied to the FHILL data.<sup>48</sup> The MDPS was characterised by the following 8 food components (based on median daily intake in g/day, energy adjusted to 2500 kcal for men and 2000 kcal for women), resulting in a score ranging from 0–8:

1. High intake of vegetables (score 1 if intake >median; score 0 if <median).
2. High intake of legumes (score of 1 if intake >median; score 0 if <median).
3. High intake of fruit/nuts (score of 1 if intake >median; score 0 if <median).
4. High intake of cereals (including bread/potatoes) (score of 1 if intake >median; score 0 if <median).
5. High monounsaturated: saturated fat ratio (score of 1 if intake >median; score 0 if <median).
6. Low intake of dairy (score of 0 if intake >median; score 1 if <median).
7. Low intake of meat/fish (score of 0 if intake >median; score 1 if <median).
8. Moderate ethanol (score of 0 if intake >25 g women >50 g men; score 1 if <25 g women <50 g men).

The design of the score favoured a more plant based (vegetarian) diet for which there was considerable evidence showing reduced mortality and morbidity from chronic diseases (in contrast to a more animal-based diet).<sup>49</sup> The MDPS values range from 0 (minimal conformity to the traditional Mediterranean diet pattern) to 8 (maximal conformity to the traditional Mediterranean diet pattern). Of the 5 ethnic groups studied, the elderly Greek Australians had the lowest mortality after 5 years, the greatest intake of legumes (86 g/day) and the highest MDPS (81% had scores  $\geq 4$ ).<sup>50</sup> Kouris-Blazos et al analysed the effect of the MDPS on survival in Greek Australians. Subjects with scores  $\geq 4$  (i.e. had a more plant-based diet which included legume-based meals several times a week usually in place of meat) had a 50% reduced risk of death after 5 years.<sup>51</sup>

Darmadi-Blackberry et al investigated the relative importance of the individual components of the MDPS using data from FHILL (n=785) which included the 5 ethnic cohorts (Swedes, Japanese, Anglo-Celtic Australians, Greek Australians, Greeks in Greece) aged over 70.<sup>50</sup> In this analysis, fish was separated from meat into its own group resulting in 9 food groups. Using Cox proportional hazard regression analysis it was found that a higher legume intake was the most predictive dietary predictor of longevity, regardless of ethnicity, with a 7–8% reduction in risk of death for every 20 g increase in daily legume

intake ( $p=0.02$ ). Supporting this relationship are results from the Greek EPIC prospective cohort study, which found that a higher MDPS was associated with a 14% lower mortality among the 23,349 participants during 8.5 years, and that high legume consumption was calculated to contribute to almost 10% of the protective effect of the diet.<sup>52</sup> A 6-8 year longitudinal follow-up study in Taiwan on over 5770 men and women showed that a bean-free diet may play a role in developing metabolic syndrome in both genders and is a significant predictor of all-cause mortality in women but not evident in men.<sup>53</sup>

The Blue Zones project has also provided insight into the importance of legumes for longevity. In 2004, journalist Dan Buettner teamed up with National Geographic and longevity researchers to identify pockets around the world where people live measurably longer. In these "Blue Zones" they found that people reach age 100 at rates 10 times greater than the average in the United States. Five "Blue Zones" were identified: the Adventist community in Loma Linda in California; Nicoya Peninsula in Costa Rica; Sardinia in Italy; Ikaria in Greece; and Okinawa in Japan. This essentially anthropological study documented the food habits and lifestyle characteristics that might explain their longevity. These observations have been documented in several books, on their website [www.bluezones.com](http://www.bluezones.com) and in a paper by Panagiotakos et al on the elderly Ikarians.<sup>54</sup> Lessons can be learned from these communities which have been reported to consume about 95% of their daily kilojoules from plant foods, with legumes being consumed twice a week in place of meat in Ikaria and almost daily in other Blue Zone areas. No studies to date have investigated the intake of lupins and longevity

### **Cardiovascular disease (CVD) and risk factors**

Observational studies indicate people who eat legumes are less likely to develop heart disease and intervention trials have demonstrated legumes can reduce CVD risk factors such as cholesterol, blood pressure, inflammation, blood sugars and weight.<sup>55</sup> The US-based population study (NHANES I Epidemiologic Follow-up Study) reported that legume consumption four times or more a week (compared with less than once a week) was associated with a 22% lower risk of CHD and an 11% lower risk of CVD.<sup>56</sup>

The Japan Collaborative Cohort Study followed over 60,000 adults for 13 years and found the highest bean intake (4.5 serves a week) was associated with a 16% reduction in total CVD risk and a 10% reduction in total mortality.<sup>57</sup> Similarly a meta-analysis by Afshin et al, concluded that 4 weekly 100-g servings of legumes was associated with 14% lower risk of total IHD.<sup>58</sup> A randomised intervention study conducted in Spain, the Prevención con Dieta Mediterránea (PREDIMED), on 7,447 high risk participants (with no history of CVD) demonstrated that consuming a Mediterranean diet that included at least 3 serves of legumes a week reduced the risk in the incidence of developing an initial major CVD event by 30%.<sup>59</sup>

Since 1999 the US FDA has permitted food manufacturers to claim that foods high in soy protein may help lower heart disease risk by lowering cholesterol and re-

cent meta-analyses continue to support this relationship. A 2005 meta-analysis of 23 trials using intact soy isoflavones found an LDL cholesterol lowering effect of 5%, independent of initial cholesterol levels.<sup>60</sup> A 2008 systematic review concluded that around 25 g of soy protein daily from soy milk or tofu (about 2-3 serves a day) significantly reduces total and LDL cholesterol.<sup>61</sup> A meta-analysis in 2011 of 43 trials concluded that regular consumption of 15 to 30 g of soy protein daily for between three and eight weeks reduced LDL by 5.5% and triglycerides by 10.7% and increased HDL cholesterol by 3.2% compared to controls.<sup>62</sup> One cup of soy milk plus a vegetarian food product (e.g. soy sausages) provides 19 g of soy protein.

Non-soy legumes have also been shown to lower cholesterol. A 2011 meta-analysis of clinical trials investigating non-soy legumes reported significant decreases in total cholesterol, LDL-cholesterol and triglycerides (mainly in men with high cholesterol). The 10 trials studied the effects of 80-440 g/day ( $\frac{1}{2}$  to 2 cups) of chickpeas, pinto beans, baked beans, navy beans as well as flour from ground beans. All studies reported net decreases in total cholesterol with a mean reduction of 5.5% in total cholesterol and 6.6% in LDL cholesterol.<sup>63</sup> A systematic review of 26 randomised controlled trials ( $n=1037$ ) concluded that diets emphasizing dietary pulse intake at a median dose of 130 g/d (about 1 serving daily) significantly lowered LDL cholesterol levels compared with the control diets (mean difference -0.17 mmol/L, 95% CI: -0.25 to -0.09 mmol/L).<sup>64</sup>

Legumes also appear to beneficially affect other CVD risk factors. A 2014 systematic review reported that 2 serves of legumes (~162 g/day) significantly lowered blood pressure in people with and without hypertension.<sup>65</sup> Non-soy legume intake has been found to significantly lower CRP (inflammation marker) concentrations<sup>66,67</sup> and one large scale cohort study reported an association between soy isoflavones and reduced CRP.<sup>68</sup> Legumes are high in dietary fibre, beneficial fatty acids, isoflavones and antioxidants, which may be helping to lower cholesterol and in turn would help reduce the risk of CVD. Legumes are also good sources of saponins and phytosterols which may assist with decreasing absorption of cholesterol from the gut.<sup>26</sup>

### **Australian sweet lupin (*Lupinus angustifolius*)**

The effects of consuming lupin (Australian sweet lupin and other varieties) on cardio-metabolic parameters have been explored in both human and animal studies and recently reviewed.<sup>69</sup> These studies have used both whole lupin, lupin enriched foods as well as isolated lupin protein and lupin dietary fibre. There have been numerous human studies undertaken utilising both lupin protein and fibre isolates and whole lupin flour, and investigating their effects on blood lipids. Weisse et al compared the effects of lupin protein versus casein on plasma lipoproteins in hypercholesterolemic individuals and showed that the group consuming lupin protein obtained a greater improvement in LDL to HDL cholesterol-ratio from baseline to week six, relative to the group consuming casein (-0.24 (95% CI: -0.007, -0.479;  $p<0.05$ )).<sup>70</sup> Sirtori et al asked participants to consume two bars containing lupin

protein isolate and cellulose per day over a four week period and observed significant reductions in total serum cholesterol in the lupin group ( $-4.2\%$ ,  $p < 0.05$ ).<sup>71</sup> In the search for the mechanisms behind these effects animal studies have revealed that lupin protein may act by modulating the transcription levels of genes involved in lipid metabolism<sup>72,73</sup> and that it may up-regulate LDL receptors in human hepatoma cells.<sup>74</sup> Bähr et al have also recently showed that incorporation of 25 g/d of lupin protein into a variety of complex food products lowers total and LDL cholesterol, triacylglycerols, homocysteine, and uric acid in hypercholesterolemic individuals with the observed effect being stronger in individuals with severe hypercholesterolemia. They suggested that arginine might be responsible for some, but not all of the positive effects observed.<sup>75</sup>

Several studies have also utilized isolated lupin kernel fibre. One demonstrated that the consumption of an additional 17–30 g/day of lupin fibre on top of baseline intake resulted in significant reductions in both total and LDL cholesterol.<sup>70</sup> Another recent study by Fechner et al observed a significant improvement in both total ( $-0.55$  mmol/L) and LDL cholesterol ( $-0.45$  mmol/L) after 4 weeks of lupin fibre (25 g/d) supplementation versus control, also demonstrating that lupin fibre has a more pronounced effect on blood lipids in comparison to other dietary fibres.<sup>76</sup> The authors proposed that lupin's effect on blood lipids may be mainly related to the impact of its fibre on short chain fatty acid formation rather than simply the result of bile acid binding.<sup>76</sup>

Given the positive independent results from both lupin protein and fibre isolates on blood lipids it would be expected that consumption of whole lupin, including both the fibre and protein fractions, would result in even greater benefits, however research done to date has not demonstrated this.

Hodgson et al utilized whole lupin flour in a normocholesterolemic group consuming lupin flour-enriched (40% wheat flour replacement) bread versus control white bread (4 slices/d) over 16 weeks, and observed no significant differences in serum total cholesterol (mean  $-0.08$ , 95% CI  $(-0.38, 0.22)$  mmol/L), or triglycerides ( $0.09$   $(-0.10, 0.21)$  mmol/L).<sup>77</sup> This was also supported by Belski et al's findings from a 12-month study of normocholesterolemic individuals, with no differences observed between lupin (4–6 slices/d plus 1–2 biscuits, 40% wheat flour replacement) and control group blood lipid concentrations at 4 and 12 months.<sup>78</sup>

It is important to note that participants in both of these studies were normocholesterolemic, therefore this research needs to be repeated in hypercholesterolemic populations to see if it is effective, as animal studies suggest that this is important. Rat studies reveal that the cholesterol lowering effects appear to be much stronger in rats fed a hypercholesterolemic diet, compared to those fed a normolipemic diet<sup>72</sup> and is further supported by studies utilizing soy protein, which demonstrate a definite hypocholesterolemic effect only in hypercholesterolemic individuals, with minimal or no changes observed in normocholesterolemic individuals.<sup>79</sup> This emphasizes one of the many complexities involved in researching this area, demonstrating the need for more research.

In line with other pulse studies reviewed by Jayalath et al numerous studies have reported significant effects of lupin consumption on blood pressure.<sup>65</sup> Whilst human studies exploring the effects of whole lupin flour are sparse they do demonstrate a consistent improvement in blood pressure. A 16 week intervention trial by Lee et al ( $n=74$ ) investigated the effect of lupin flour-enriched bread on blood pressure using 24-hour ambulatory blood pressure measurements.<sup>80</sup> They observed significant differences in systolic blood pressure ( $-3.0$  mm Hg), diastolic blood pressure ( $-0.6$  mm Hg) and pulse pressure ( $-3.5$  mm Hg) over the 16-week trial with the consumption of a diet incorporating lupin flour-enriched bread (4 x 40–45-g slices/d, 40% wheat flour replacement) compared to a control white bread. Another 12-month randomized controlled trial also explored blood pressure and demonstrated significant reductions in the mean 24-hour systolic ( $-1.3$  mm Hg) and diastolic ( $-1$  mm Hg) blood pressures in the lupin group (4–6 slices/d plus 1–2 biscuits, 40% wheat flour replacement) relative to control at 12 months but not 4 months.<sup>78</sup> Whilst these reductions may appear modest, the participants in this study were normotensive at baseline and hypertensive individuals are more likely to show a clinically significant reduction in blood pressure with such intervention. On a population level such changes would also be considered significant, as a large meta-analysis has previously suggested that if population systolic blood pressure could be reduced by as little as 2 mm Hg in middle aged adults it would translate to a 10% lower stroke mortality in this group.<sup>81</sup>

Understanding the exact mechanism/s of lupin's action on blood pressure has not been as straight forward. Whilst early animal work suggested that lupin protein may be the active component which can slow the development of hypertension and improve endothelial function,<sup>82</sup> it is unlikely to be the only mode of action. Specifically, the high arginine content of lupin has been suggested as a potential mechanism<sup>83</sup> acting as a precursor for nitric oxide synthesis, which enables improvement in vascular tone leading to a reduction in blood pressure.<sup>82</sup> It has also recently been demonstrated that lupin enzymatic protein hydrolysates have high ACE-inhibitory activity,<sup>83</sup> providing a further potential pathway for its blood pressure reduction properties. However, another recent 4 week human intervention study by Fechner et al observed a significant drop in systolic blood pressure with lupin fibre supplementation (25 g/d) versus control by 4 mmHg, suggesting that it may not be the protein fraction alone resulting in the blood pressure reduction benefits observed with lupin consumption.<sup>76</sup> Hence it could be the combined effects of lupin protein and fibre leading to optimal outcomes, potentially via effects on the microbiome.<sup>84</sup>

### Diabetes

Legumes have been shown to improve short-term blood glucose control, and as part of a low GI diet are linked to long-term improvements in HbA1c and reduced risk of non-insulin dependent diabetes (NIDDM). In a large prospective study in China, where more than 64,000 women were followed-up for more than four years, legume intake and incidence of NIDDM was inversely related.<sup>85</sup> The highest quintile of intake was 65 g a day and soy foods



made up 40% of the total legume content of the diets. While soybeans alone had a clear protective effect (with a relative risk of 0.53), other non-soy legumes were also associated with significantly lower risk (relative risk = 0.76).

A meta-analysis of 11 trials reported that consumption of up to half a cup of legumes per day for more than four weeks significantly reduces fasting blood glucose and insulin levels.<sup>20</sup> When they were consumed as part of a low-GI (glycaemic index) diet, they also significantly lowered HbA1c or fructosamine for up to 52 weeks in both diabetic and non-diabetic individuals. Subsequent randomised controlled studies have also shown that legumes, as part of a low GI diet, are linked to long-term improvements in HbA1c and reduced risk of developing NIDDM.<sup>19,86</sup> Legumes appear to improve insulin sensitivity even if diets are high in total carbohydrate and high GI. Simpson et al conducted a randomized cross-over study of 18 NIDDM and 9 insulin dependent diabetics. They were put on a high carbohydrate diet plus added legume fibre for 6 weeks followed by a low carbohydrate diet. The former diet improved all aspects of diabetic control compared to the latter diet without legume fibre.<sup>87</sup> Similarly a study on 17 individuals with NIDDM showed that eating 50 g of carbohydrate as beans (pinto beans or dark red kidney beans or black beans) with white long grain rice attenuated the glycemic response compared to 50 g of carbohydrate as white long grain rice alone.<sup>88</sup> Legumes are not only able to reduce blood glucose levels immediately after they are eaten but also at a subsequent meal later in the day or even the following day, helping to reduce the risk of developing diabetes. This is known as the second meal effect.<sup>21,22</sup>

High meat diets have also been linked to diabetes, possibly via their adverse effects on the microbiome.<sup>89</sup> A cross-over randomized clinical trial on 31 individuals with NIDDM were advised to replace two servings of red meat with legumes, 3 days a week. The substitution of red meat for legumes significantly decreased fasting blood glucose ( $p=0.04$ ), fasting insulin ( $p=0.04$ ), triglyceride concentrations ( $p=0.04$ ) and low-density lipoprotein cholesterol ( $p=0.02$ ), which were independent from BMI change.<sup>90</sup>

#### Australian sweet lupin (*Lupinus angustifolius*)

A number of acute studies have demonstrated improvements in postprandial glycaemia and insulinaemia with lupin consumption. Lee et al have previously shown that lupin-enriched foods can acutely reduce both glucose and insulin levels postprandially.<sup>91</sup> More recently Dove et al demonstrated that adding lupin or soy to a carbohydrate-rich beverage reduces glycaemia acutely in NIDDM individuals.<sup>92</sup> They undertook a randomized, controlled, cross-over trial ( $n=24$ ) with participants consuming either a beverage containing 50 g glucose, or 50 g glucose plus lupin kernel flour (12.5 g fibre and 22 g protein), or 50 g glucose plus soya isolates (12.5 g fibre and 22 g protein), over three separate sessions. The post-beverage glucose response 4 hours following consumption was lower and the post-beverage insulin and C-peptide responses were higher for both lupin and soy drinks compared to glucose control. Additionally they observed a lower insulin re-

sponse with lupin consumption compared with soy ( $p=0.013$ ).

Longer term studies exploring lupin's impact on glycaemia have had varied results. Hodgson et al reported that 4 months of regular consumption of an *ad libitum* lupin-enriched diet did not alter fasting glucose or insulin concentrations in overweight individuals.<sup>77</sup> However, a more recent, 12 month, weight loss study involving a similar population of overweight men and women, found that a lupin flour-enriched diet significantly lowered fasting insulin concentrations by 16% and 21%, and Homeostasis Model Assessment (HOMA) scores by 30% and 33% at 4 and 12 months, respectively.<sup>78</sup> In this study the participants were following an energy restricted diet for 4 months and then an *ad libitum* diet for the following 8 months, hence it may be that the beneficial effects are only observed with energy restriction/weight loss, but that these improvements can then be maintained following weight loss. It is important to note that the lack of observed effect on blood glucose levels is likely to be related to the normoglycaemic population selected for both studies (baseline BSL <6.0 mmol/L).

The specific mechanisms responsible for the observed improvements remain unclear. It has previously been demonstrated that the addition of lupin flour to baked products lowers its Glycaemic index.<sup>93</sup> Given that lupin is high in both protein and dietary fibre, both may be contributing to the observed improvements in insulin sensitivity. In regards to lupin kernel fibre, several studies have previously reported small, non-significant reductions in the glucose response in both healthy<sup>94</sup> and NIDDM individuals.<sup>95</sup> The more interesting proposed mechanism is that of conglutin- $\gamma$ . Conglutin- $\gamma$ , is a glycoprotein found in lupin, and animal studies have demonstrated that it can lead to a significant plasma glucose reduction when orally administered to rats in glucose overload trials.<sup>96</sup> The authors of this animal research have suggested that this observed effect may be through an insulin-mimetic cellular mechanism of action. This idea is supported by another recent animal study.<sup>97</sup> They also suggest that the mechanism of action also makes conglutin- $\gamma$  a potential insulin-sensitizing compound worth exploring further.

#### Weight management and satiety

A review by Williams et al concluded that more studies are needed to elucidate if legumes help with weight control.<sup>98</sup> For example, in the US National Health and Nutrition Examination Survey 1999-2002 of 1475 adults, eating legumes was associated with lower BMI, 23% reduced risk of increased waist circumference and 22% reduced risk of obesity compared to those who did not eat beans.<sup>18</sup> A cross-sectional study of adults in Iran reported that the risk of being centrally obese was significantly lower in men falling within the highest quartile of legume intake (30 g a day).<sup>99</sup> A small trial in Mexico with overweight diabetic participants compared a low-GI (with more carbohydrates being provided from legumes) and a high-GI diet. Those consuming more legumes had improved glycaemic control and greater weight loss.<sup>100</sup>

More recent studies have shown that legumes (3-5 cups cooked legumes a week) included in an energy-controlled

diet resulted in significant reductions in weight between 3.6 kg and 8.1 kg over six to eight weeks compared to diets without legumes.<sup>101</sup> Legumes have also been shown to increase satiety both acutely and at the next meal. In a meta-analysis by Li et al healthy people felt 31% fuller after eating about 160 g legumes compared with an energy-matched control meal, but no effect was reported on second meal intake.<sup>102</sup> An Australian study found that consuming four 300 g cans of chickpeas a week resulted in significantly higher levels of satiety and improved bowel function.<sup>103</sup>

#### **Australian sweet lupin (*Lupinus angustifolius*)**

Whilst an acute study<sup>91</sup> has previously demonstrated an effect of lupin (40% inclusion rate in bread) on increased satiety and satiation which can lead to reduced food intake and potentially weight loss, longer term studies have not reported significant weight/fat loss.<sup>77,78</sup> The effect of legumes on satiety is probably due to their high content of fibre and protein and due to their low GI.<sup>20</sup>

#### **Cancer, bowel health and microbiome**

The World Cancer Research Report in 2006 concluded that there was limited evidence on legume consumption and reduced risk of cancer.<sup>104</sup> However, research since then suggests otherwise. A meta-analysis of observational studies found that eating legumes is associated with a reduced risk of bowel cancer.<sup>105</sup> Two meta-analyses in 2009<sup>106</sup> and 2011<sup>107</sup> concluded that there is evidence that legumes provide protection against prostate cancer, lung cancer, breast and colorectal cancers, although much of the evidence is limited to the effect of soy intake.

Population studies indicate soy consumption may help prevent breast cancer and reduce risk of re-occurrence in breast cancer survivors.<sup>108-115</sup> There have been concerns about soy isoflavones and their effect on breast tissue as well as their interaction with the hormonal therapy tamoxifen due to findings from in-vitro and animal studies.<sup>116</sup> However the relevance of these results in women consuming soy foods is not established.<sup>117</sup> Two meta-analyses concluded that there is a 14-25% reduced risk of breast cancer with high soy intakes.<sup>118,119</sup> A 2012 study on over 9500 US and Chinese breast cancer survivors were followed up for 7 years to investigate the influence of soy food and breast cancer outcomes, including women taking tamoxifen.<sup>120</sup> Contrary to previous concerns, eating soy food was found to be safe for breast cancer survivors. Women who consumed the highest intakes of soy foods had a 29% reduced risk of breast cancer specific mortality and a 36% reduced risk of recurrence compared to those with the lowest intake of soy foods. Lupin is naturally low in phytoestrogens making it an alternative if there is concern.<sup>121</sup>

An analysis of the Nurses' Health Study, involving 34,467 US women, found that those who consumed four or more servings of legumes a week had a lower incidence of colorectal adenomas than women who reported consuming one serving or less.<sup>122</sup> Similarly the Shanghai Women's Health Study, found that women in the highest tertile of soy consumption had a 33% lower colorectal cancer risk.<sup>107</sup>

The mechanisms by which legumes reduce carcinogenesis are not well understood. Some candidate compounds that could be playing a role include the polyphenols,<sup>27</sup> resistant starch and galacto-oligosaccharides (GOS). The latter two compounds are fermented by colonic bacteria to produce short chain fatty acids which have been shown to promote the death of colorectal cancer cells.<sup>16,123</sup>

Legumes can cause increased flatulence which can be a deterrent for some. A study by Winham and Hutchins showed that not everyone is affected and that the bowel adjusts to a regular intake in just a few weeks.<sup>124</sup> In this study, healthy adults were asked to eat half a cup of legumes (pinto beans, black-eyed peas or navy beans) or carrots each day for eight to twelve weeks. In the first week half the participants reported increased gas but by the second week over 70% reported that the increase in gas had dissipated.<sup>124</sup> However, some legumes high in GOS may cause bowel pain and excessive bloating in people with irritable bowel syndrome.<sup>125</sup>

Growing evidence suggests that the human microbiome is critical in regards to health. It has been linked to multiple health outcomes including; cardiovascular disease, obesity, colitis, colorectal cancer and even psoriasis.<sup>126</sup> Emerging research on the gut microbiome implicates legumes as important prebiotics that can favourably alter bowel flora to produce metabolites that alter production of gut hormones which in turn reduce appetite.<sup>47</sup> Adherence to the Mediterranean diet pattern (high in legumes) has also been associated with beneficial microbiome-related metabolomic profiles such as increased levels of faecal short chain fatty acids, Prevotella bacteria and some fibre-degrading Firmicutes. Subjects with lower adherence to the Mediterranean diet pattern had higher urinary excretion of the potential cardio-toxicant, trimethylamine oxide.<sup>127</sup>

#### **Australian sweet lupin (*Lupinus angustifolius*)**

Like the rest of the legume family, lupin acts as a prebiotic in the human gut. Smith et al demonstrated that lupin kernel fibre modified fecal microbiota in humans, increasing the levels of *Bifidobacterium* spp. and lowering *C. ramosum* and *C. spiroforme* levels over a 28 day trial by with the inclusion of an extra 17-30 g of lupin fibre per day.<sup>128</sup> Another trial by Fechner et al observed that supplementation of 25 g of lupin fibre a day led to a significant increase in the formation of short-chain fatty acids and that *L. angustifolius* also reduced fecal concentrations of total and secondary bile acids by 16%, increased primary bile-excretion and decreased fecal pH which are all beneficial in reducing risk factors for colorectal cancer.<sup>129</sup> These studies demonstrate that legumes, and more specifically lupin, may play an important role in the modification of the microbiome which may lead to improvements in health outcomes.

#### **PROCESSING, FERMENTING, SPROUTING, COOKING**

For much of human history and most of humankind, legumes have been consumed as fermented foods or early shoots and sprouts. These often have nutritious value over and above the seeds on which they are based or compared to the unfermented form. For example, fermented soy

beans (natto) are a better source of vitamin K-2 than unfermented soy, with a functional profile which includes the prevention of arterial calcification.<sup>130</sup> Other fermented soy products like tempeh and miso have also been linked to a reduction in incidence and severity of chronic diseases such as cardiovascular, breast and prostate cancers, menopausal symptoms and bone loss.<sup>131</sup> These products can be sourced locally and processed at the household level making them accessible and affordable. This form of preparation is also energy-efficient, avoiding the costly demands for firewood and the prolonged cooking times, typical of bean-based diets in some meso-American and African cultures. Barriers to cooking may in themselves adversely affect health.<sup>132</sup> Shoots are also generally more phytonutrient-dense than the parent seed (see Table 2). Sprouts contain Ca, Fe, Zn, at levels about the same as the seeds while protein and fat content can be lower in sprouts. Vitamin C, thiamin, niacin, and riboflavin contents are higher in sprouts than seeds, with vitamin C showing the greatest increase. Nutrient levels of sprouts compare favourably with other fresh vegetables.<sup>133</sup> Domestic production and minimal cooking add value to this form of legume consumption as does fermentation. As a general rule, unfermented unsprouted legumes should not be eaten uncooked (except sweet lupins). Most legumes (except lentils, split peas, black eyed beans) need soaking overnight in plain water (and this water should be discarded) followed by extensive boiling to reduce the antinutritional factors and resulting bowel discomfort.

#### Australian sweet lupin (*Lupinus angustifolius*)

Lupin has a wide diversity of species which are often grouped into either 'Old world' species usually referring to those from the Mediterranean and East African regions, including *L. angustifolius* or 'New world' species referring to American regions.<sup>134</sup> The genus *Lupinus* consists of hundreds of species, of which only a few have been domesticated including; *L. albus*, *L. angustifolius*, *L. luteus* and *L. mutabilis*. *L. albus* and *L. luteus* are grown mainly in Europe, especially the Mediterranean region, while *L. angustifolius* is largely produced in Australia. *L. albus* has been used as food since the pre-Roman and Greek times. Traditionally, lupin beans prepared in brine, or soaked/boiled, dried and salted, have been a popular snack food in the Middle East and Mediterranean regions of the world. In modern times Europeans often consume lupins in a variety of ways including as a salad ingredient, or as a snack food once the beans have been boiled, cooled and salted. However most of the lupin traditionally used in Europe was a bitter variety which required some preparation (mainly soaking in brine and boiling) to remove/reduce the high (potentially toxic) alkaloid content. Less bitter strains, like *L. angustifolius*, often referred to as sweet lupins, were developed in Australia in the last five decades by selective plant breeding to minimize this extensive preparation and cooking requirement. It is important to note that the development of lupin as a food crop in Australia is relatively recent. Lupins are not native to Australia, with numerous species of lupins introduced into Australia by botanists in the mid 19<sup>th</sup> century, therefore they are not a food likely to have been traditionally consumed by indigenous Australians. In the 1980s

and 1990s, Australian State Departments of Agriculture encouraged the use of lupins as green manure.<sup>135</sup> The modern history of lupin development in Australia can be in large part attributed to the career of Western Australian plant breeder Dr John Gladstones, who commenced a breeding program on *L. angustifolius* (a naturally lower alkaloid lupin variety) in 1958. In order to easily distinguish *L. angustifolius* from other varieties he intentionally selected white flowers and seeds as markers. Later he intercrossed natural varieties with wild types from Europe to develop even better lines with even lower alkaloid content.<sup>136</sup> The more neutral flavour of Australian sweet lupin (compared to the more bitter varieties) makes it ideally suited for use by the food industry.<sup>137</sup> Sweet lupins are made into flour and flakes. To date, sweet lupin has been utilised in bread, biscuit and pasta products to improve their nutritional value by reducing their refined carbohydrate content and more than doubling the amount of dietary fibre and protein. It has also been made into milk and even ice cream products just to name a few of its commercial uses.<sup>136</sup> Lupin flake (flaked lupin kernels) is a more recent ingredient available to the market and is being used for more versatile recipes including as a meat crumb, for dips and falafels. It is important to note that, from the available evidence reviewed in this paper, the health benefits of sweet lupin appear to be present only when the foods utilised have been substantially fortified/enriched with lupin (>20% inclusion rate).

#### CONCLUSION

Legume and pulse consumption is a usual and beneficial part of the human diet and contributory to health. This paired with pulses' ability to feed the planet sustainably and provide an inexpensive source of essential nutrients and bioactively favourable phytochemicals demonstrates the role they can play in the food system. FAO has selected 2016 as the International Year of Pulses which will highlight the health and environmental benefits they offer. There is now evidence that regular consumption of pulses has multiple health benefits including those on heart health, gastrointestinal health and cancer prevention with improved all-cause mortality. Sweet lupins, a legume crop found in Australia, is a legume with a growing body of evidence of the health benefits with one of the highest natural combined sources protein and dietary fibre and lowest levels of anti-nutritional factors, making the protein and its nutrients more bioavailable and negating the need for soaking and cooking. This means, that unlike other legumes, sweet lupin can therefore be eaten raw, increasing its versatility. In Australia, lupin flour and flakes are added to baked goods like gluten free bread, biscuits and cakes, uncooked to smoothies and dips and to many other products. Sweet lupin consumption has been demonstrated to have a favourable impact on blood lipids, blood pressure, insulin sensitivity and the gut microbiome. The outstanding question about sweet lupins is that, compared with other legumes, there is limited information about their long-term effects and the associated longevity. Except to say that, historically, its bitter cousins have been used as a snack food in areas of the Middle East, the Mediterranean and the Americas renowned for their longevity. That the dietary inclusion of legumes, such as

lupin, can improve cardiovascular risk and other health prospects merits greater consumer awareness and food behavioural change than presently obtains. Ancient grains like quinoa have been popularised in recent times, with limited evidence for health benefits, while lupins have promising effects on energy balance and cardio-metabolic risk. Whilst the evidence obtained to date on various health benefits (heart disease, blood pressure, blood lipids, cancer) of legumes is strong, more long-term randomised controlled trials and cohort studies are needed to confirm the emerging evidence that legumes in general increase longevity, perhaps because of improved weight management, long-term blood glucose control, diabetes prevention and gut microbiome health.

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#### AUTHOR DISCLOSURES

Dr Kouris-Blazos and Dr Belski are both involved in consulting to industry on food product development and the utilisation of pulses to optimise their nutritional content. Dr Kouris-Blazos has also developed a range of commercial healthy cookies, several of which utilise lupin flour as an ingredient. No funding was provided for this review.

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## Review Article

# Health benefits of legumes and pulses with a focus on Australian sweet lupins

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## 豆科植物及豆類如澳洲甜羽扇豆的健康效益

**背景和目的：**第 68 屆聯合國大會宣布 2016 年為國際豆類年。這是一個好時機來查證豆科植物，特別是澳洲甜羽扇豆，對人體健康的現有證據。**方法與研究設計：**搜尋 Medline、Pubmed、Cochrane 圖書館資料庫以找出橫斷性/流行病學研究、隨機控制試驗（RCTs）以及系統性回顧文獻。**結果：**最強的證據是食用豆類與降低大腸直腸癌，以及食用黃豆食物與降低低密度脂蛋白膽固醇的關聯性。再者，流行病學研究及 RCT 建議每週以豆類取代幾餐以肉為主的餐食，透過腸道菌相潛在有益作用，對於延壽、糖尿病、心血管疾病及體重控制有正面影響。甜羽扇豆在豆類中的獨特性是它們有合併最高量的可消化植物性蛋白（38%）及膳食纖維（30%）。不同於其它豆類，他們的抗營養因子低，所以不需要浸泡/烹調，即可生食。甜羽扇豆可降低血壓、改善血脂及胰島素敏感性，並對腸道菌相有利。越來越多對豆類的興趣，特別是甜羽扇豆，如作為改善烘焙食物（特別是無麩質）營養價值的成分，及取代肉類的創新產品。**結論：**豆類是最傳統飲食中的一部份。豆類，包括甜羽扇豆，可在健康維持上扮演有用的角色。

**關鍵字：**豆類、豆科植物、甜羽扇豆、健康、心血管