Optimizing the plant-based diet

Jim I Mann DM, PhD, FRACP, FFPHM

Department of Human Nutrition, University of Otago, Dunedin, New Zealand

Any attempt to optimize a plant-based diet necessitates an identification of the features of the diet which confer benefit as well as any which may be associated with detrimental effects. The former task is more difficult than might be assumed as there is no doubt that some of the apparent health benefits observed amongst vegetarians are a consequence of environmental determinants of health which characterize groups of people who choose vegetarian diets, rather than dietary practices. This review will consider the major health benefits of plant-based diets, the specific foods or nutrients which confer the benefits as far as can be ascertained from present knowledge, potential nutrient deficiencies associated with a plant-based diet and nutritional strategies that can be employed to prevent any such deficiencies.

Key words: vegetarian, nutrients, lifestyle.

Health benefits of vegetarian diets

Five prospective epidemiological studies have compared mortality outcomes in vegetarians with a meat-eating control cohort.[1–5] One of the most striking features of such studies is the extremely favourable outcome of *all* participants. For example, in the Oxford study of vegetarians and healthy meat-eating control group,[5] the standardized mortality ratios (SMR) for all participants (using national mortality data for England and Wales as the standard) suggested appreciable lower than expected mortality experience with regard to all-cause mortality as well as mortality from ischaemic heart disease (IHD) and all malignant neoplasms (Table 1). Although two key determinants of health at the population level (cigarette smoking and obesity) clearly operated as risk factors for IHD and total mortality (Table 2), their relative infrequency may well explain the low overall mortality (Table 3).

A fairly recent meta-analysis has aggregated data from five prospective studies comparing mortality experience in vegetarians with that in groups of non-vegetarians with a shared interest in healthy living or a similar social/religious background.[6] Table 4 shows the significant reduction in IHD death rate ratios in vegetarians compared to meat eaters in both men and women, following standardization for age, smoking and study. The reduction in men was about 30% and that in women about 20%. The reduction in cerebrovascular disease and lung cancer deaths almost achieved statistical significance, but there was no difference in the other cancer sites (including breast cancer – not shown). The reduction in IHD is reflected in the reduction in total mortality, and it is important to note that there are no causes of mortality that appear to be significantly elevated in vegetarians compared with meat eaters. The biological validity of the data are enhanced by the facts that the reduction in IHD and cerebrovascular disease mortality in vegetarians was particularly evident in younger individuals (Table 5) and in those who had been vegetarians for a longer time (Table 6). It was also possible to compare (on the basis of the data in four of the five studies) those who ate meat regularly with occasional meat eaters (semi-vegetarians), fish eaters and true vegetarians. Once again the data are consistent and significant only for IHD (Fig. 1). Thus it seems likely that IHD is reduced in vegetarians as a result of their dietary practices. Previous studies of Seventh Day Adventist vegetarians have suggested dramatic reductions in cancer incidence at most sites when compared with the population at large (Table 7).[7] It is not clear whether this is due to differences in incidence and mortality or whether non-dietary environmental factors that are characteristic of health-conscious individuals account for this apparent discrepancy between incident and mortality data. The latter would seem to be the more likely explanation.

It is important to consider benefit also in terms of other conditions that may be less frequent direct causes of death, but which may cause appreciable morbidity or perhaps act as risk factors for more serious conditions. Probably the most clearly documented examples of such conditions are diabetes,[8] hypertension,[9] diverticular disease[10] and gallstones.[11]

Table 1. Standardized mortality ratios (SMR) using national mortality data for England and Wales for all causes, ischaemic heart disease and all malignant neoplasms for the entire cohort (vegetarians and meat eaters) in the Oxford Vegetarian Study (525 deaths, 143 000 person-years at risk)

	Men		Women	
	SMR	95% CI	SMR	95% CI
All cause mortality	0.48	0.42–0.54	0.57	0.50–0.64
Ischaemic heart disease	0.44	0.35–0.56	0.46	0.35–0.61
All malignant neoplasms	0.56	0.44–0.69	0.75	0.63–0.81

CI, confidence interval.

Correspondence address: Prof. Jim Mann, Department of Human Nutrition, University of Otago, PO Box 56, Dunedin, New Zealand.
Tel: 64 3 479 7719; Fax: 64 3 479 7958
Email: jim.mann@stonebow.otago.ac.nz

Foods or nutrients that explain health benefits

There is no longer disagreement regarding the reduced rates of the medical conditions described earlier amongst vegetarians and that major environmental health determinates, such as not smoking, are not solely responsible for the observed benefits. There is, however, still considerable debate as to whether the vegetarian diet is conducive to good health or whether the effects are due to specific nutrients or combinations of nutrients consumed by vegetarians. Not surprisingly, relatively few studies have direct bearing on this issue. Mann *et al.* have utilized the data obtained from simple food frequency questionnaires in an attempt to explain the reduced cardiovascular risk observed amongst vegetarians in the Oxford Vegetarian Study.[12] Fig. 2 shows death rate ratios (and 95% confidence intervals) for IHD for selected dietary factors, adjusted for age, sex, smoking and social class, in subjects with no history of cardiovascular disease or diabetes at recruitment. Each dietary or nutrient variable is divided into tertiles. The area of each square is proportional to the number of deaths from IHD in that group. These data show a clear relationship between IHD and intakes of eggs and cheese, as well as total animal fat, saturated animal fat and dietary cholesterol.

Interestingly there was no direct association between eating meat and IHD, but it should be noted that relatively few individuals in the entire cohort of volunteers ate meat daily. It is also relevant to note that none of the foods and nutrients that might have been expected to confer a protective effect against IHD appeared to operate in this study. For example, there was no trend towards risk reduction with increased consumption of fish, fruit, green or yellow vegetables or dietary fibre. Thus it would appear that a reduction in food items rich in saturated fatty acids and dietary cholesterol, probably operating via a reduction in total and low-density lipoprotein (LDL) cholesterol,[13] are major determinants of the reduced cardiovascular risk in this study.

It should be noted that the food frequency questionnaire employed in this study is a relatively crude one. It may not have been sufficiently sensitive to have detected the cardioprotective effect of several unsaturated fatty acids, dietary fibre, anti-oxidant nutrients and folic acid that are present in various plant oils, fish, fruits and vegetables.[12] Furthermore, it is conceivable that in the cohort as a whole, the overall consumption of these foods was too high to demonstrate a risk-reducing gradient when considering mortality over a range of

Table 3. Number (%) of men and women with various lifestyle related characteristics and with pre-existing disease at the time of entry to the Oxford Vegetarian Study

	Men	Women
No. subjects	4102	6700
Median age at entry (years)	34	33
Diet group		
Meat eater	2147 (52.3)	2751 (41.1)
Semi-vegetarian	387 (9.4)	962 (14.4)
Vegetarian/vegan	1568 (38.2)	2987 (44.6)
Smoking habits		
Never smoked	1787 (43.6)	4021 (60.0)
Ex-smoker	1302 (31.7)	1588 (23.7)
Current smoker		
< 10 Cigarettes/day	531 (12.9)	487 (7.3)
≥ 10 Cigarettes/day	482 (11.8)	604 (9.0)
Body mass index (kg/m^2)		
< 20	592 (14.4)	1777 (26.5)
20–	1560 (38.0)	2804 (41.9)
22.5–	1259 (30.7)	1425 (21.3)
≥ 25	691 (16.8)	694 (10.4)
Pre-existing disease*		
No	3832 (93.4)	6148 (91.8)
Yes	270 (6.6)	552 (8.2)

*Angina, heart disease, hypertension, diabetes or stroke.

Table 4. Overall death rate ratios and 95% confidence intervals for vegetarians compared with non-vegetarians in the meta-analysis of five studies. Adjusted for age, smoking and sex

Cause of death	Men (n = 30 148)	Women (n = 46 024)
Ischaemic heart disease	0.69 (0.56–0.84)	0.80 (0.67–0.95)
Cerebrovascular disease	0.77 (0.57–1.02)	0.98 (0.80–1.20)
Lung cancer	0.62 (0.36–1.06)	1.08 (0.70–1.68)
Stomach cancer	0.88 (0.51–1.53)	1.32 (0.62–2.80)
Colorectal cancer	0.99 (0.70–1.41)	1.02 (0.78–1.35)
Other causes	1.00 (0.84–1.18)	0.98 (0.83–1.15)
All causes	0.86 (0.73–1.01)	0.93 (0.82–1.06)

Table 2. Death rate ratio (95% confidence interval) according to smoking habits, body mass index and social class for participants without pre-existing disease at the time of recruitment to the Oxford Vegetarian Study

	Ischaemic heart disease		All causes of death	
	No. deaths (64)	Death rate ratio	No. deaths (392)	Death rate ratio
Smoking habits				
Never smoked	22	100	173	100
Ex-smoker	25	131 (73–237)	131	112 (88–141)
Current smoker				
< 10 Cigarettes/day	5	128 (47–344)	34	125 (86–181)
≥ 10 Cigarettes/day	12	464 (224–959)**	54	241 (176–329)**
Body mass index (kg/m^2)				
< 20	8	158 (61–409)	81	141 (106–189)*
20–22.4	9	100	107	100
22.5–24.9	23	269 (124–584)*	117	135 (103–176)*
≥ 25	24	392 (180–851)**	87	155 (116–207)**

Significance of difference from reference category: *2P < 0.05; **2P < 0.01.
Data adjusted for age, sex and for other variables listed.

consumption. There is considerable evidence from experimental and epidemiological studies that such foods and nutrients protect against both IHD and cancer at several sites.[12]

In the study of Adventists' frequency of consumption of wholemeal bread and nuts accounted for the beneficial effect of the diet,[14] and in a study of health-food shoppers, fresh fruit appeared to confer particular benefit.[15]

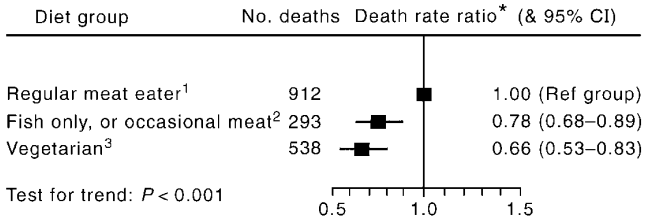

Figure 1. Ischaemic heart disease death rate ratios by diet group in the meta-analysis of prospective studies including vegetarians and non-vegetarians.[6] 1, meat eaten at least once per week; 2, fish but not meat eaten, or meat eaten less than once per week; 3, no meat or fish eaten. CI, confidence interval.

Table 5. Ischaemic heart disease death rate ratios for vegetarians versus non-vegetarians by age at death

Age at death (years)	Death rate ratio (95% CI)	No. deaths
< 65	0.55 (0.35–0.85)	259
65–79	0.69 (0.53–0.90)	1086
80–89	0.92 (0.73–1.16)	919

Death rate ratios are adjusted for age (within categories), sex and smoking, and for study using a random effects model.
CI, confidence interval.

Table 6. Ischaemic heart disease death rate ratios by duration of diet

Duration of diet	Death rate ratio (95% CI)	No. deaths
Non-vegetarian	1.00 (Reference group)	1530
Vegetarian ≤ 5 years	1.20 (0.90–1.61)	49
Vegetarian > 5 years	0.74 (0.60–0.90)	625

Death rate ratios are adjusted for age, sex and smoking, and for study using a random effects model. Duration was unknown for 1785 vegetarians.
CI, confidence interval.

Of all the individual potential protective foods, consumption of nuts is of particular interest. Nuts appear to confer identical protective effects in vegetarians and non-vegetarians and seem to be inversely related also to all-cause mortality, thus possibly promoting longevity as well as reducing cardiovascular risk.[16] There are several possible mechanisms by which nuts might protect against IHD including the favourable fatty acid profile, their cholesterol lowering potential and the presence of a wide range of bioactive compounds.[17]

It should also be noted that vegetarians tend to be leaner even than their health-conscious associates (Fig. 3). Obesity defined as a Body Mass Index (BMI) > 30 kg/m^2 was present in 1% of about 2000 vegetarian women and in none of around 1000 male vegetarians.[18] The higher intake of dietary fibre and lower intake of animal fat appeared to explain the difference between vegetarians and non-vegetarians. The very low frequency of obesity could contribute substantially to the reduced rates of IHD and other conditions amongst vegetarians.

Potential deleterious effects of a vegetarian diet

Much has been written regarding the potentially deleterious effects of vegetarian diets. These include anaemia due to iron or B12 deficiency, and deficiencies of calcium, zinc, vitamin D, vitamin B6 and total energy.[19] However, the objective evidence for clinically significant deficiencies is limited. Of course vegetarians have low intakes of haem iron and a high intake of dietary fibre and phytate; thus the phytate to zinc

Table 7. Standardized morbidity ratios (and confidence interval) of selected incident cancers in men and women in the Adventist cohort

Site	Men	Women
All cancer	0.73 (0.66, 0.82)	0.92 (0.84, 1.00)
Stomach	0.50 (0.23, 0.95)	0.16 (0.03, 0.52)
Large intestine	0.64 (0.45, 0.88)	0.76 (0.54, 0.98)
Bronchus and lung	0.25 (0.16, 0.37)	0.32 (0.20, 0.58)
Prostate	1.25 (1.03, 1.51)	–
Breast	–	0.91 (0.76, 1.07)

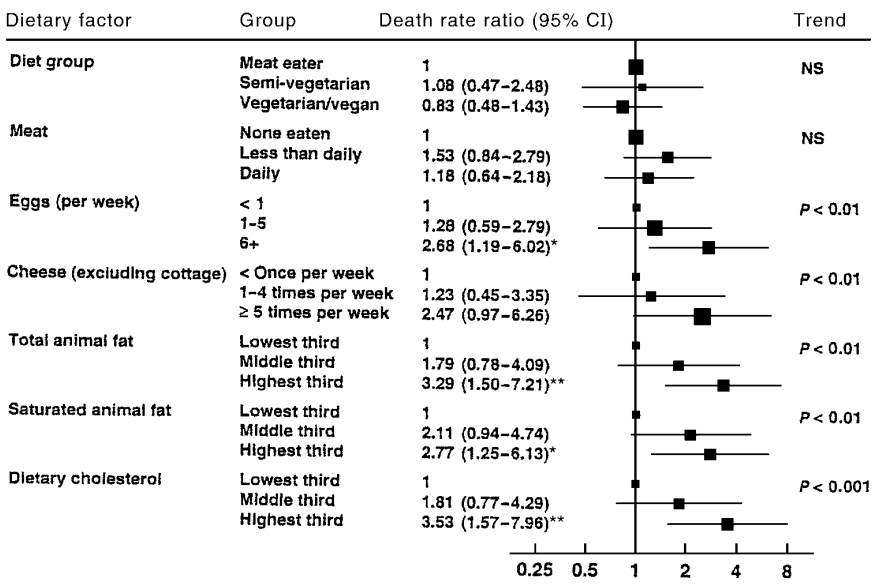

Figure 2. Death rate ratios for ischaemic heart disease (with 95% confidence intervals (CI)) for selected dietary variables (adjusted for age, sex, smoking and social class) for subjects with no evidence of pre-existing disease at the time of recruitment into the Oxford prospective study of vegetarians and meat eaters. NS, not significant.

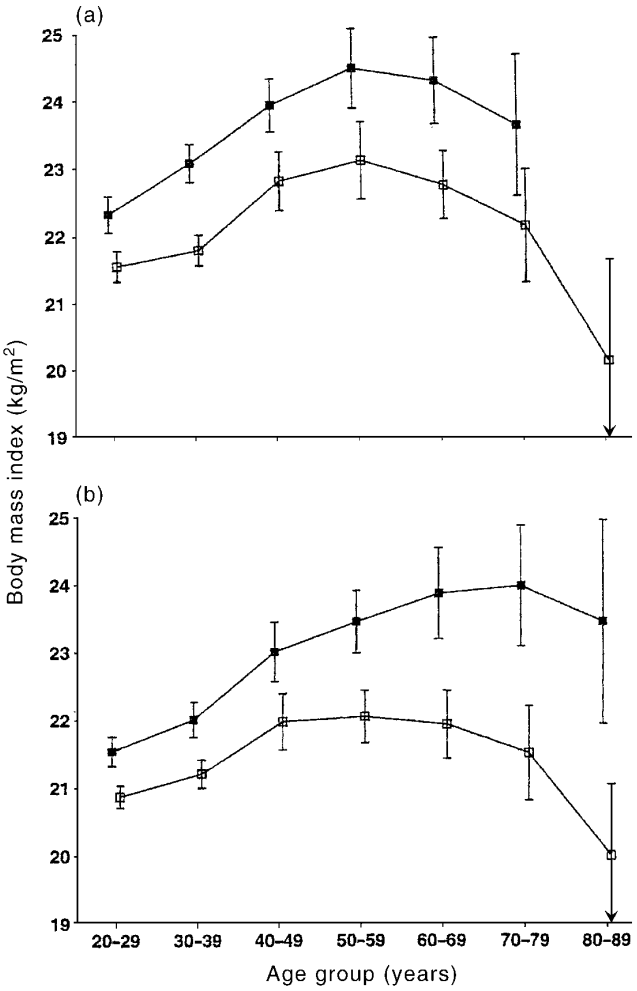

Figure 3. Mean body mass index for (a) men and (b) women according to diet group and age (showing 95% confidence intervals (CI)) in the Oxford Vegetarian Study. (■) Meat eater; (□) non-meat eater. Note: there were no male meat eaters aged 80–89 years.

molar ratio is increased, possibly to the extent that absorption may be impaired. Thus the risk of impaired iron and zinc status is real.[20] Vitamin B12 intake is more difficult to assess accurately but is likely to be reduced, especially in vegans.[21] In practice, clinical anaemia has not been found to be more common in vegetarians than non-vegetarians as the frequency of iron-deficiency anaemia, especially in young women, is related more closely to blood loss than to dietary intake.[21] However, iron stores that are assessed on the basis of serum ferritin levels are lower in vegetarians than non-vegetarians, resulting in increased risk of iron deficiency as well as other potential adverse clinical outcomes.[21]

Lacto-ovo vegetarians can obtain sufficient calcium from milk and milk products to ensure they achieve recommended intakes. However, those relying entirely on a plant-based diet will need to ensure they have substantial intakes of soy-based products or use fortified foods or supplements to ensure adequate intakes. Calcium bioavailability is low in many other plant sources of calcium. Inadequate energy intakes for achieving optimum growth potential in infancy and childhood would appear to be at least a possibility when children are weaned onto a relatively low-energy dense diet that is typical of vegetarians and vegans. This has been reported in isolated instances in vegetarians and in at least one cohort of vegans, but generally satisfactory catch-up growth occurs later.[22] Rickets has been reported in Asian vegetarian children, but this may be due to insufficient exposure to sunlight rather than a dietary deficiency.

Table 8. Nutrient density: vegan children compared with omnivorous children

	Vegan children	British children 7–12 years
Energy percentage RDA	83.00	82.00
Fat (g/4.2 MJ)	35.00	41.10
Fibre (g/4.2 MJ)	21.80	9.20
Calcium (mg/4.2 MJ)	270.00	400.00
Iron (mg/4.2 MJ)	12.60	5.70
Zinc (mg/4.2 MJ)	4.30	3.90
Thiamin (mg/4.2 MJ)	0.98	0.64
Riboflavin (mg/4.2 MJ)	1.00	0.82
Vitamin B12 (μg/4.2 MJ)	1.30	1.64
Vitamin D (μg/4.2 MJ)	1.10	0.90
Vitamin E (mg/4.2 MJ)	4.40	2.50

RDA, recommended dietary allowance.

Optimizing the plant-based diet

The vast majority of people opting to follow a vegetarian diet will intuitively or as a result of present nutritional recommendations be achieving appreciable health benefits from their dietary and other lifestyle practices (not smoking, undertaking regular physical activity). Their diets are likely to include a variety of grains, legumes, vegetables, fruits, nuts and seeds, vegetable oils and, if they are not vegans, eggs, milk and dairy products. Food pyramids and other teaching proposals that are appropriate for vegetarians have been devised.[23] Indeed, even vegan children seem to be able to achieve a diet that differs little in terms of important nutrients, other than calcium and vitamin B12, from non-vegetarian children (Table 8).[22]

However, amongst young people who may opt to follow a vegetarian or vegan lifestyle but have not acquired appropriate patterns of eating during childhood and adolescence, there is a real possibility both of deficiencies and of not achieving the health benefits usually associated with a plant-based diet. A diet dominated by vegetarian high-fat fast food (e.g. pizza, some 'vegeburgers'), confectionary products, synthetic sugary beverages and perhaps a few baked beans, clearly has little to commend it.

While the general guides presently available will help to ensure both adequacy and the health benefits of a plant-based diet, some aspects are worthy of special emphasis. It is important for adult vegetarians to be reminded that the most convincing documented benefits appear to be derived from a low intake of saturated fatty acids and dietary cholesterol, which help to reduce cardiovascular disease, obesity and its consequences. While the benefits of consuming a wide range of plant-based foods is unquestionable, it is perhaps worth mentioning that nuts appear to occupy a special role in the vegetarian diet. Amongst young women in particular, it is important to ensure adequate intakes of iron, zinc and calcium, and dietary strategies have been devised to improve the diets of young vegetarian women in these respects.[24–26]

Amongst vegans, B12 and iodine supplementation may be required.[26,27]

In infancy and childhood similar issues apply. The benefits of prolonged breast feeding cannot be overemphasized, as is the need to ensure sufficient energy requirements for growth in the context of a bulky diet that has the potential to restrict energy intakes. Iron deficiency can result in impaired psychomotor development and the same strategies described for adults should be applied in childhood. Vegan children will benefit from calcium-supplemented soya milk and other products and may require B12 and iodine supplementation. Vegetarian and vegan diets tend to have a relatively high ratio of *n*-6/*n*-3 fatty acids and, in particular, a deficiency of docosahexaenoic oil, which is believed to be important in the development of the retina and central nervous system. However, the extent to which specific recommendations for individual fatty acids are required has not been clearly established.

References

1. Snowdon DA. Animal product consumption and mortality because of all causes combined, coronary heart disease, stroke, diabetes, and cancer in Seventh-day Adventists. Am J Clin Nutr 1988; 48 (Suppl.): 739–748.
2. Burr ML, Sweetnam PM. Vegetarianism, dietary fiber, and mortality. Am J Clin Nutr 1982; 36: 873–877.
3. Beeson WL, Mills PK, Phillips RL, Andress M, Fraser GE. Chronic disease among Seventh-day Adventists, a low-risk group. Cancer 1989; 64: 570–581.
4. Frentzel-Beyme R, Claude J, Eilber U. Mortality among German vegetarians: First results after five years of follow-up. Nutr Cancer 1988; 11: 117–126.
5. Thorogood M, Mann J, Appleby P, McPherson K. Risk of death from cancer and ischaemic heart disease in meat and non-meat eaters. BMJ 1994; 308: 1667–1671.
6. Key TJ, Fraser GE, Thorogood M, Appleby PN, Beral V, Reeves G, Burr ML, Chang-Claude J, Frentzel-Beyme R, Kuzma JW, Mann J, McPherson K. Mortality in vegetarians and non-vegetarians: A collaborative analysis of 8300 deaths among 76 000 men and women in five prospective studies. Public Health Nutr 1998; 1(1): 33–41.
7. Mills PK, Beeson WL, Phillips RL, Fraser GE. Cancer incidence among California Seventh-day Adventists, 1976–1982. Am J Clin Nutr 1994; 59(Suppl.): S1136–S1142.
8. Snowdon DA, Phillips RL. Does a vegetarian diet reduce the occurrence of diabetes? Am J Public Health 1985; 75: 507–512.
9. Margetts BM, Beilin LJ, Vandongen R, Armstrong BK. Vegetarian diet in mild hypertension: A randomised controlled trial. BMJ 1986; 293: 1468–1471.
10. Gear JSS, Ware AC, Fursdon P, Mann JI, Nolan, DJ, Bodribb AJM, Vessey MP. Symptomless diverticular disease and intake of dietary fibre. Lancet 1979; I: 511–514.
11. Pixley F, Wilson D, McPherson K, Mann JI. Effect of vegetarianism on development of gallstones in women. BMJ 1985; 291: 11–12.
12. Mann JI, Appleby PN, Key TJ, Thorogood M. Dietary determinants of ischaemic heart disease in health conscious individuals. Heart 1997; 78: 450–455.
13. Law MR, Wald NJ, Wu T, Hackshaw A, Bailey A. Systemic underestimation of association between serum cholesterol concentration and ischaemic heart diesase in observational studies: Data from the BUPA study. BMJ 1994; 308: 363–366.
14. Fraser GE, Sabaté J, Beeson WL, Strahan TM. A possible protective effect of nut consumption on risk of coronary heart disease. Arch Intern Med 1992; 152: 1416–1428.
15. Key TJA, Thorogood M, Appleby P, Burr ML. Dietary habits and mortality in 11 000 vegetarians and health conscious people. BMJ 1996; 313: 775–779.
16. Sabaté J. Nut consumption, vegetarian diets, ischaemic heart disease risk, and all-cause mortality: Evidence from epidemiologic studies. Am J Clin Nutr 1999; 70(Suppl.): S500–S503.
17. Kris-Etherton PM, Yu-Poth S, Sabaté J, Ratcliffe HE, Zhao G, Etherton TD. Nuts and their bioactive constituents: Effects on serum lipids and other factors that affect disease risk. Am J Clin Nutr 1999; 70(Suppl.): S504–S511.
18. Appleby PN, Thorogood M, Mann JI, Key TJ. Low body mass index in non-meat eaters: The possible roles of animal fat, dietary fibre and alcohol. Int J Obesity 1998; 22: 454–460.
19. Dwyer JT. Nutritional consequences of vegetarianism. Annu Rev Nutr 1991; 11: 61–91.
20. Donovan UM, Gibson RS. Iron and zinc status of young women aged 14–19 years consuming vegetarian and omnivorous diets. J Am College Nutr 1995; 14: 463–472.
21. Alexander D, Ball MJ, Mann J. Nutrient intake and haematological status of vegetarians and age-sex matched omnivores. Eur J Clin Nutr 1994; 48: 538–546.
22. Sanders TAB. Vegetarian diets and children. Paediatr Clin North Am 1995; 42: 935–964.
23. Haddad EH, Sabaté J, Whitten CG. Vegetarian food guide pyramid: A conceptual framework. Am J Clin Nutr 1999; 70(Suppl.): S615–S619.
24. Gibson RS, Donovan UM, Heath A-LM. Dietary strategies to improve the iron and zinc nutriture of young women following a vegetarian diet. Plant Foods Hum Nutr 1997; 51: 1–16.
25. Weaver CM, Proulx WR, Heaney R. Choices for achieving adequate dietary calcium with a vegetarian diet. Am J Clin Nutr 1999; 70(Suppl.): S543–S548.
26. Appleby PN, Thorogood M, Mann JI, Key TJA. The Oxford Vegetarian Study: An overview. Am J Clin Nutr 1999; 70(Suppl.): S525–S531.
27. Hokin BD, Butler T. Cyanocobalamin (vitamin B-12) status in Seventh-day Adventist ministers in Australia. Am J Clin Nutr 1999; 70(Suppl.): S576–S578.