The Cancer Council Australia

POSITION STATEMENT

Fruit, vegetables and cancer prevention

The population recommendation of at least two serves of fruit and five serves of vegetables daily is appropriate for cancer prevention.

Key messages/recommendations

- The Cancer Council recommends that people eat a variety of different fruit and vegetables to obtain maximum benefits.
- Fruit and vegetables are high in nutrients that are potentially protective against cancer. They also play an important role in weight management. As obesity is a known risk factor for cancer of the colon, breast (in post-menopausal women), endometrium, kidney and oesophagus, fruit and vegetables may also protect against cancer indirectly by helping to maintain a healthy body weight.
- Although there has been a slight weakening of the evidence supporting the role of fruit and vegetables in reducing the risk of some cancers, overall the evidence is suggestive of a protective effect. Recent studies show that fruit and vegetables are protective against oral, laryngeal, oesophageal, colorectal and lung cancers.
- The association of fruit and vegetable consumption on stomach cancer risk remains inconclusive, however fruit may possibly be protective. Fruit consumption also appears to provide protection against bladder cancer.
- Fruit and vegetable consumption does not appear to be associated with a lower risk of prostate, breast or ovarian cancer. However, one meta-analysis suggests that tomato consumption may reduce the risk of prostate cancer.
- The Cancer Council supports the Australian Dietary Guidelines that recommend eating plenty of fruit and vegetables, and the population recommendation of at least two serves of fruit and five serves of vegetables daily.
- Consuming a variety of fruit and vegetables in important, as knowledge is incomplete about how different nutrients may reduce cancer risk.
- Fruit and vegetables are best consumed fresh and whole (i.e. not in a supplement form) and consumption of both cooked and raw vegetables is recommended.
- For people already diagnosed with cancer, there is some evidence that a diet high in fruit and vegetables is not of significant benefit, but is unlikely to be harmful. The Cancer Council recommends the general community guidelines of two serves of fruit and five serves of vegetables daily for cancer survivors.

Background

The International Agency for Research on Cancer (IARC) concluded that 5-12% of cancers could be attributed to low fruit and vegetable consumption.[1] Australian data suggests that 2% of cancers were attributable to low consumption of fruit and vegetables.[2] In terms of health care costs, it has been estimated that low vegetable intake (<4 serves per day) accounts for 17% of the cost of bowel cancer, 2% of the cost for breast cancer, and 9% of the cost of lung and of prostate cancer.[3] Twenty one percent of the cost of lung cancer and 4% of the cost of breast cancer has been attributed to lower fruit intake (<3 serves per day).[3]

The protective effects of fruit and vegetables against cancers, as well as other diseases such as coronary heart disease and type 2 diabetes, has led to the promotion of fruit and vegetables consumption as a national public health priority.[4]

Fruit and vegetables also play an important role in weight management due to their low energy density, high fibre content and capacity to displace higher energy foods from the diet. Obesity is a known risk factor for cancer of the colon, breast (in post-menopausal women), endometrium, kidney and oesophagus.[5] Emerging evidence suggests that obesity is also linked to cancer of the pancreas, gallbladder, thyroid, ovary and cervix as well as non-Hodgkin's lymphoma and multiple myeloma.[6] Therefore fruit and vegetables may reduce the risk of cancer directly through the provision of specific anti-carcinogenic agents and indirectly through their role in weight management.

Rationale

The purpose of this position statement is to evaluate and summarise the epidemiological evidence linking fruit and vegetables with primary cancer prevention. In order to do this, The Cancer Council recently completed a review of the literature.

The review specifically looked for meta-analyses and systematic reviews that examined the relationship between fruit and vegetable consumption and cancer risk. In addition to the meta-analyses and systematic reviews identified, several cohort studies were also considered, including the published results of the European Prospective Investigation into Cancer and Nutrition (EPIC) study. A major strength of EPIC is the wide range of fruit and vegetable intakes that have been assessed.

Fruit and vegetables

Fruit and vegetables are high in nutrients that are potentially protective against cancer. Anti-carcinogenic activity may be provided by nutrients such as fibre, vitamins, minerals, antioxidants and phytochemicals, which are chemicals found in plants such as flavonoids, carotenoids and lignans. It is probably a combination of these nutrients and phytochemicals found together in whole foods that helps to reduce the risk of chronic diseases rather than one anti-cancer component, although many different mechanisms have been proposed.[7] Single nutrients identified from the analysis of epidemiological studies have usually been unsuccessful when investigated further in trials, making the whole food approach more appropriate to prevention advice.

Fruit and vegetables in particular have attracted much research attention for their cancer protective effects, and accordingly, many cancer associations worldwide, together with a number of National Dietary Guideline committees have recommended a daily intake of 5-7 serves of fruits and vegetables to reduce cancer risk.

Views on fruit and vegetables in major cancer prevention reports

Several major reports that have investigated the relationship between fruit and vegetable intake and cancer risk show that there has been a shift in the strength of the evidence over the last 10 years. These reports indicate that the evidence appears to be somewhat weaker than previously thought (Table 1). On the whole, evidence that vegetables are protective is stronger than for fruits, but this may simply reflect the generally greater consumption of vegetables worldwide or the different mix of nutrients obtained from them.

Table 1. Conclusions from the major cancer prevention reports regarding the cancer protective effect of fruit (f) and vegetables (v).

Organisation Review	Highest Evidence Convincing	Moderate Evidence Probable	Lower Evidence Possible
WCRF/AICR (1997)[8]	Mouth (f&v) Pharynx (f&v) Oesophagus (f&v) Stomach (f&v) Colon & rectum (v) Lung (f&v)	Larynx (f&v) Pancreas (f&v) Breast (f&v) Bladder (f&v)	Ovaries (f&v) Cervix (f&v) Endometrium (f&v) Thyroid (f&v) Liver (v) Prostate (v) Kidney (v)
COMA (1998)[9]	Oesophagus (f&v)	Stomach (f&v) Colon & rectum (v)	Breast (f&v)
WHO/FAO (2003)[10]		Oral Cavity (f&v) Oesophagus (f&v) Stomach (f&v) Colon & rectum (f&v)	
IARC (2003)[1]		Oesophagus (f&v) Stomach (f) Colon & rectum (v)	Mouth (f&v) Pharynx (f&v) Larynx (f&v) Kidney (f&v) Colon and rectum (f) Bladder (f) Stomach (v) Lung (v) Ovary (v)

In 1997, the World Cancer Research Fund and the American Institute of Cancer Research (WCRF/AICR) jointly published an extensive, global review of the role of food and nutrition in the prevention of cancer.[8] The conclusions by WCRF/AICR relating to the protective effect of fruits and vegetables can be seen in Table 2.

Many of the views expressed in the 1997 WCRF/AICR report were also reflected in an extensive review published the previous year, which found that fruit and vegetables appeared to protect against cancer of the mouth, pharynx, oesophagus, stomach, colon, pancreas, endometrium and lung.[11]

This review also noted that vegetables in general, and raw vegetables in particular, appear to be the outstanding protective categories.[11] They specifically identified allium

vegetables (including onions, garlic and leeks), carrots, green vegetables in general, cruciferous vegetables (such as cabbage, cauliflower, broccoli, brussel sprouts, Chinese cabbage and bok choy) and tomatoes as strongly protective.

Table 2. WCRF/AICR conclusions relating the cancer protective effect of particular types of fruits and vegetables.[8]

Fruit or Vegetable	Convincing	Probable	Possible
Vegetables	Colon		Prostate Liver Kidney
Cruciferous vegetables		Colon & rectum Thyroid	
Allium vegetables	Stomach		Colon
Green vegetables	Lung		Oesophageal Colon Breast
Green leafy vegetables	Stomach	Mouth/oral Pharyngeal	
Raw Vegetables	Stomach		
Tomatoes	Stomach		Lung
Carrots		Stomach Lung Bladder	Mouth/oral Rectum
Citrus fruits	Stomach		Mouth/oral Oesophageal

The United Kingdom Department of Health Committee of the Medical Aspects of the Food Supply (COMA) reviewed the evidence concerning the potential protection afforded by fruit and vegetables against the development of cancer in 1998.[9] No *strong*[#] association was found between fruit and vegetable consumption and cancer at any site, while a *moderate* association was noted for cancers of the stomach, colon and rectum (Table 1). This is in contrast to WCRF/AICR, who rated the evidence of an association for cancer of the mouth, pharynx, stomach, colon, rectum and lung as *convincing* (Table 1). Although they did not agree on the strength of evidence for each, these two major international organisations did agree that increased consumption of fruits and vegetables is associated with a reduced risk for cancers of the oesophagus, stomach, colon, rectum and breast (Table 1).

The different conclusions reached in the WCRF/AICR and COMA reports relate to their relative weighting of different types of evidence. In the 1998 COMA report, prospective cohort studies carried more weight than case control or ecological studies, and mechanistic studies of induced tumours in standard animal models were not included. In 1997, the WCRF/AICR expert review panel examined *in vitro* studies and animal trials as well as ecological, case-control and cohort studies in human populations. At the time of the WCRF report, there were only a limited number of cohort studies that had reported on fruit and vegetable intake and cancer risk.

[#] Note that COMA used a different rating system when assessing the evidence

Results published in 2001 from the EPIC study showed that significant health gains are made from even a small increase in fruit and vegetable intake.[12] Increasing intakes of fruit and vegetables by just 50g a day (equivalent to 2/3 cup cooked vegetables or 1/3 of a piece of fruit) was associated with a reduction in cancer risk of around 20%.[12]

In 2003, The World Health Organisation (WHO) suggested that a high intake of fruit and vegetables *probably* reduces the risk of cancers of the oral cavity, oesophagus, stomach and colorectum (Table 1).[10] WHO recommended an intake of at least 400g of fruit and vegetables daily (in addition to potatoes). However, they found that support for a broad and strong protective effect of higher vegetable and fruit intake had weakened with results from recent prospective studies.

Similarly, IARC found that a high intake of vegetables *probably* reduces the risk of oesophageal and colorectal cancer, while a high intake of fruit *probably* reduces the risk of oesophageal and stomach cancer (Table 1).[1] However the IARC rated the evidence for an association between vegetable intake and cancer of the mouth, pharynx, larynx, kidney, stomach, lung and ovary and the evidence for an association between fruit intake and cancer of the mouth, pharynx, larynx, kidney, colorectum and bladder as *possible.*[1]

The conclusions from WHO and IARC differ from the previous reviews by WCRF/AICR and COMA because of the inclusion and consideration of more prospective studies published since these original reviews were undertaken. In recent years it has been increasingly apparent that the protective association between fruit and vegetable intake and cancer is much stronger in case-control studies than in cohort studies. Furthermore, randomised controlled trials involving fruit and vegetable intake, notably for colorectal cancer, have not demonstrated any benefit. Case-control studies are known to be prone to recall and selection bias, however the length of follow-up in cohort studies can also potentially limit the interpretation of their results.

In 2004, the IARC reviewed the evidence relating to cruciferous vegetables, isothiocyanates and indoles and found that for human studies:[13]

- There is limited evidence that eating cruciferous vegetables reduces the risk for cancers of the stomach and lung
- There is inadequate evidence that eating cruciferous vegetables reduces the risk for cancers at all other sites
- There is inadequate evidence to assess the independent effects on human cancer risk of isothiocyanates and indoles, as opposed to their combined effects with other compounds in cruciferous vegetables.

The recent evidence supporting a direct role for fruit and vegetables in cancer prevention appears to be mixed. In 2007, WCRF will publish an update of their conclusions regarding fruit and vegetables in their *Report on Food, Nutrition Physical Activity and the Prevention of Cancer*. The report will review all the available science relating to cancer prevention. It is hoped that this report will further clarify the role of fruit and vegetables in cancer prevention.

In the meantime, The Cancer Council NSW has sought to review the recent literature regarding the role of fruit and vegetables and cancer protection to help clarify the discrepancies that appear in the literature.

Vegetables, fruit and cancer prevention: evidence from epidemiology studies

All Cancers combined

The association between fruit and vegetable intake and the risk of major chronic disease was examined in the Nurses Health Study and Health Professionals Study.[14] There was no association between the consumption of fruit and vegetables and cancer incidence. The relative risk (RR) of cancer based on a continuous measure for the increment of five serves per day of total fruit and vegetable intake was 1.00 (95% confidence interval (CI)= 0.95-1.05).[14] Interestingly, five serves of fruit and vegetables were protective against cardiovascular disease (RR= 0.88, 95% CI= 0.81-0.95).[14]

Oral Cancer

In 2006, a meta-analysis of 15 case-control studies and one cohort study found a statistically significant reduction in oral cancer risk for each portion of fruit (combined adjusted odds ratio (OR)= 0.51, 95% CI= 0.40-0.65) and vegetable consumed (combined adjusted OR= 0.50, 95% CI= 0.38-0.65).[15] Similar results were found when results were pooled from 12 studies that adjusted for age, sex, smoking and alcohol intake (OR for fruit= 0.49, 95% CI= 0.39-0.63; OR for vegetables= 0.43; 95% CI= 0.31-0.59).[15] Interestingly citrus fruit appeared to provide greater protection than overall fruit consumption (OR= 0.38, 95% CI 0.26-0.56).[15]

A meta-analysis completed in 2003 found that in case-control studies (nine studies on fruit and seven studies on vegetable consumption), both fruit (RR= 0.53, 95% CI= 0.37-0.76) and vegetables (RR= 0.84, 95% CI= 0.67-1.07) provided protection against oral cancer, with fruit providing a statistically significant result.[16]

Laryngeal cancer

In the only meta-analysis identified for laryngeal cancer, fruit consumption provided a significant protective effect (RR= 0.73, 95% CI= 0.64-0.84), while vegetables appeared to provide a very small non-significant reduction in risk (RR= 0.92, 95% CI= 0.83-1.02) in case-control studies (five studies on fruit and seven studies on vegetable consumption).[16]

This meta-analysis was very limited, as out of the eight case-controls studies identified, one was excluded from the analysis on both fruit and vegetables, while two were excluded from the analysis on fruit. The authors point out that the first study was excluded because study subjects were classified into only two categories of consumption, however it is not known why the other two studies were excluded.

Oesophageal cancer

The effect of fruit and vegetable intake on the risk of adenocarcinoma of the oesophagus was investigated as part of the EPIC study.[17] A non-significant inverse association was found for total vegetable consumption (hazard ratio (HR)= 0.71, 95% CI= 0.34-1.48), total fruit intake (HR= 0.94, 95% CI= 0.49-1.80) and citrus fruit consumption (HR= 0.73, 95% CI= 0.39-1.37).[17]

An increase of 100g per day of total vegetables (HR= 0.72, 95% CI= 0.32-1.64), total fresh fruit (HR= 0.84, 95% CI= 0.60-1.17) and citrus fruit (HR= 0.77, 95% CI= 0.46-1.28) also showed a non-significant inverse association with oesophageal cancer.[17] A

limitation of the EPIC study was that the number of oesophageal cancer cases was small, which limits the statistical power of the study.

A meta-analysis completed in 2003, which included one cohort study and 12 case-control studies, indicated a significant protective association for fruit (RR= 0.72, 95% CI= 0.62-0.83) and vegetables (RR= 0.89, 95% CI= 0.82-0.97) with oesophageal cancer.[16]

Stomach cancer

The effect of fruit and vegetable intake on the risk of gastric cancer was investigated as part of the EPIC study.[17] The range of fruit and vegetable intakes varied greatly between the lowest intakes and highest intakes. There was very little evidence for a protective association between fresh fruit (HR= 0.99, 95% CI= 0.68-1.42) and stomach cancer, while there was a non-significant inverse association for citrus fruit (HR= 0.88, 95% CI= 0.63-1.24) and a non-significant positive association for vegetables (HR= 1.15, 95% CI= 0.78-1.70) and stomach cancer.[17]

In 2005, a meta-analysis which included 14 cohort studies on the association between stomach cancer and the consumption of fruit (13 studies) and vegetables (eight studies) found a slight non-significant protective effect for fruit (RR= 0.89, 95% CI= 0.78-1.02), while only a very small non-significant inverse relationship was found for vegetable consumption (RR= 0.98, 95% CI= 0.86-1.13).[18] The strongest association was seen in those studies with a follow-up period $\geq$10 years for fruit (RR= 0.66, 95% CI= 0.73-0.93) and vegetables (RR= 0.71, 95% CI= 0.53-0.94).[18] Fruit consumption had a non-significant negative affect on mortality (RR= 0.88, 95% CI= 0.70-1.09), while vegetable consumption had a small non-significant positive affect on mortality (RR= 1.02, 95% CI= 0.78-1.33) in those studies with a follow-up period $\geq$ 10 years.[18]

A meta-analysis from 2003 included seven cohort studies and 24 case-control studies regarding fruit consumption and stomach cancer, and five cohort studies and 17 case-control studies regarding vegetable consumption and stomach cancer.[16] All but one of these cohort studies was included in the meta-analysis mentioned above.[18]

The combined analysis of case-control and cohort studies found a statistically significant protective result for both fruit (RR= 0.74, 95% CI= 0.69-0.81) and vegetable (RR= 0.81, 95% CI= 0.75-0.87) consumption.[16] Fruit (RR= 0.69, 95% CI= 0.62-0.77) and vegetable (RR= 0.78, 95% CI= 0.71-0.86) intake was significantly protective in case-control studies.[16] However, this result was weaker and non-significant in cohort studies (RR for fruit= 0.89, 95% CI= 0.73-1.09; RR for vegetables= 0.89, 95% CI= 0.75-1.05).[16]

Colorectal cancer

One meta-analysis revealed a small decreased risk of colorectal cancer, which was significant for higher intakes of fruit and vegetables when all studies were pooled (Table 3).[16] This protective effect was significantly stronger in case-control studies than in cohort studies.[16] In the analyses by cancer site (colon versus rectum), cohort studies found a significant protective effect of vegetables on colon but not rectal cancer.[16] There was insufficient data from case-control studies to calculate the RR for rectal cancer and fruit consumption. Fruit consumption showed stronger protection against rectal cancer than colon cancer in cohort studies.[16]

Table 3. Results from meta-analysis on fruit and vegetable intake showing relative risk (RR) and 95% confidence interval (CI) for colorectal cancer, where n = number of studies.[16]

Cancer	Study Type	Fruit		Vegetables	
		n	**RR (95% CI)**	**n**	**RR (95% CI)**
Colorectal	All studies	31	0.94 (0.90-0.98)	46	0.91 (0.86-0.97)
	Cohort	16	0.96 (0.90-1.01)	17	0.96 (0.90-1.05)
	Case-control	15	0.93 (0.87-0.99)	29	0.87 (0.80-0.95)
Colon	All studies	19	0.94 (0.89-1.00)	27	0.91 (0.83-1.00)
	Cohort	9	0.97 (0.91-1.04)	11	0.91 (0.86-0.96)
	Case-control	10	0.90 (0.82-0.99)	17	0.90 (0.78-1.03)
Rectal	All studies	-	-	9	0.95 (0.80-1.11)
	Cohort	5	0.88 (0.81-0.96)	5	1.06 (0.90-1.25)
	Case-control	-	-	4	0.75 (0.51-1.08)

In contrast to these results, a randomised controlled trial found that over four years those following a diet low in fat (20% of total calories) and high in fibre (18g fibre per 1000 kcal), fruit and vegetables (3.5 servings per 1000 kcal) did not have a different rate of recurrent colorectal adenomas when compared to those that were instructed to follow their usual diet and were given a brochure containing general healthy eating advice (unadjusted RR= 1.00, 95% CI= 0.90-1.12).[19] While the dietary assessment data did indicate that the intervention and control groups differed substantially in the consumption of fruit and vegetables, the intervention period was relatively short. It is also possible that dietary intervention might only affect the growth of adenomas once they occur.

Most recently, a large cohort study showed that (over a five year follow-up period) for highest verses lowest intake categories, vegetable intake was significantly associated with a reduced risk of colorectal cancer (RR= 0.82, 95% CI= 0.71-0.94), and total fruit and vegetable intake was associated with a non-significant reduced risk of colorectal cancer in men (RR= 0.91, 95% CI= 0.78-1.05).[20] In particular, green leafy vegetables were associated with a significantly lower risk of colorectal cancer in men (RR= 0.86, 95% CI= 0.74-0.99).[20] However in women, vegetable intake (RR= 1.12, 95% CI= 0.90-1.38) and total fruit and vegetable intake (RR= 1.08, 95% CI= 0.86-1.35) were associated with a non-significant increased risk of colorectal cancer.[20] Fruit intake alone was associated with a small non-significant increased risk of colorectal cancer in both men (RR= 1.06, 95% CI= 0.91-1.23) and women (RR= 1.09, 95% CI= 0.88-1.36).[20] The difference in results for men and women may be due to reporting errors, as women may be more likely to over report foods perceived as healthy.

Prostate cancer

A meta-analysis which included 10 cohort or nested case-control studies and 11 case-control studies on the association between prostate cancer and tomato, tomato products or lycopene intake showed moderate protection against prostate cancer among those

who consumed large amounts of raw tomato (RR= 0.89, 95% CI= 0.80-1.00).[21] Interestingly, cohort studies showed a greater protective effect (RR= 0.71, 95% CI= 0.57-0.87) than case-control studies (RR= 0.98, 95% CI= 0.86-1.00).[21]

A similar trend was also seen for lycopene intake.[21] The RR of prostate cancer among those who consumed large amounts of lycopene was 0.89 (95% CI= 0.81-0.98).[21] Again cohort studies showed a larger protective effect (RR= 0.84, 95% CI= 0.75-0.95) than case-control studies (RR= 0.98, 95% CI= 0.83-1.16).[21] Cooked tomatoes appeared to provide even greater protection, which could be due to increases in concentration or improved availability of lycopene (RR= 0.81, 95% CI= 0.71-0.92).[21] In addition, increasing concentrations of serum lycopene showed greater protection against prostate cancer than that of dietary lycopene intake (RR= 0.74, 95% CI= 0.59-0.92).[21] This effect was even stronger for case-control studies (RR= 0.55, 95% CI= 0.32-0.94).[21] The influence of dietary lycopene intake on serum lycopene concentrations was not explored in this meta-analysis, however other studies have shown that dietary sources of lycopene can increase serum lycopene levels and reduce oxidative stress effectively.[22]

The association between fruit and vegetable consumption and prostate cancer risk was also investigated as part of the EPIC cohort study.[23] The consumption of fruit, vegetables, cruciferous vegetables and combined total fruits and vegetables with prostate cancer risk was examined, however no significant associations were found. The RR in the highest quintile of consumption compared with the lowest quintile was 1.06 (95% CI= 0.84-1.34) for fruits, 1.00 (95% CI= 0.81-1.22) for vegetables, 1.00 (95% CI= 0.79-1.26) for fruits and vegetables combined and 1.01 (95% CI= 0.83-1.23) for cruciferous vegetables.[23]

Breast cancer

There was no significant association found between breast cancer risk and vegetable intake, fruit intake or fruit and vegetable juice consumption in the EPIC cohort study.[24] RR estimates (adjusted for breast cancer risk factors) for comparisons of the highest versus the lowest quintiles were 0.98 (95% CI= 0.84-1.14) for total vegetables, 1.09 (95% CI= 0.94-1.25) for total fruit and 1.05 (95% CI= 0.92-1.20) for fruit and vegetable juice.[24]

When vegetable intake was divided into specific groupings (leafy, fruiting, root, cabbages, mushrooms and garlic and onions) there was also no evidence for a significant inverse association between intake and breast cancer risk.[24] Adjusted RR estimates ranged from 0.98 (95% CI= 0.85-1.14) for mushrooms to 1.18 (95% CI= 1.01-1.38) for cabbage.[24]

A meta-analysis completed in 2003 found that fruit did not provide protection against breast cancer, however this was not the case for vegetables.[16] Increasing fruit consumption by 100g/day (which is approximately one serve per day) had very little association with breast cancer risk (RR= 0.99, 95% CI= 0.98-1.00), whereas increasing vegetable consumption by 100g/day did slightly lower the risk of breast cancer (RR= 0.96, 95% CI= 0.94-0.98).[16] Case-control studies showed a protective effect of vegetables (RR= 0.86, 95% CI= 0.78-0.94), but not cohort studies (RR= 1.00, 95% CI= 0.97-1.02).[16] Fruit consumption was not found to be significantly protective in either the pooled estimate from case-control studies (RR= 0.92, 95% CI= 0.84-1.01) or cohort studies (RR= 0.99, 95% CI= 0.98-1.00).[16]

Ovarian cancer

In the only meta-analysis identified, total fruit and vegetable intake was not significantly associated with ovarian cancer risk.[25] Twelve cohort studies were included in this analysis. The pooled multivariate RR comparing the highest versus the lowest quartiles of intake showed little association for total fruit (RR= 1.11, 95% CI= 0.89-1.37) and total vegetable (RR= 0.88, 95% CI= 0.71-1.09) consumption with ovarian cancer cases that occurred within the first five years.[25]

When fruit and vegetable intake were represented as per 100g/day (which is approximately one serve per day), the RR values for total fruits, total vegetables and total fruits and vegetables had no association with ovarian cancer.[25] When grouped according to classes of fruit and vegetables, no statistically significant association was found. A marginally significant association with the consumption of green leafy vegetables for a 100g increment was found (pooled multivariate RR= 0.88, 95% CI= 0.76-1.00).[25]

Lung cancer

The relationship between lung cancer and dietary carotenoids was investigated by analysing the primary data from seven large cohort studies in North America and Europe as part of the Pooling Project of Prospective Studies of Diet and Cancer.[26] The intakes of five carotenoids (α-carotene β-carotene, β-cryptoxanthin, lutein and lycopene) were inversely associated with lung cancer risk.[26] The associations were similar after adjustment for various variables but were attenuated and no longer significant after additional adjustment for smoking status, duration and quantity. Only the inverse association between β-cryptoxanthin intake and lung cancer risk remained statistically significant (RR= 0.76, 95% CI= 0.67-0.86, p <0.001).[26] This result did not change after adjustment for intakes of vitamin C, folate, other carotenoids or multivitamin use, and was also consistent for smoking status. Therefore foods high in β-cryptoxanthin, such as orange juice, oranges and papaw,[27] may modestly lower the risk of lung cancer.

The effect of fruit and vegetable consumption and lung cancer risk was also investigated as part of the EPIC study.[28] There was a significant inverse association between fruit consumption and lung cancer risk, but no association was found for vegetable consumption after adjustment for age, smoking, height, weight and gender. The HR for lung cancer and fruit consumption was 0.60 (95% CI= 0.46-0.78, p value <0.01).[28] This relationship was strengthened when lung cancers diagnosed in the first two years of follow-up were excluded from the analysis (HR 0.50, 95% CI= 0.36-0.70).[28] The HR for lung cancer and vegetable consumption was 1.00 (95% CI= 0.76-1.30).[28] There was a non-significant inverse association between leafy vegetables and lung cancer risk (HR= 0.89, 95% CI= 0.66-1.19), and a non-significant positive association between cruciferous vegetables and lung cancer risk (HR= 1.21, 95% CI= 0.92-1.60).[28]

When data was divided into smoking status (current, ex-smokers, life-long non-smokers), fruit consumption provided a significant inverse association with lung cancer for smokers (HR= 0.51, 95% CI= 0.35-0.73) and life-long non-smokers (HR= 0.33, 95% CI= 0.13-0.83).[28] There was a small non-significant positive relationship seen for fruit consumption and lung cancer for ex-smokers (HR= 1.07, 95% CI= 0.65-1.76).[28] Vegetable consumption appeared to have a non-significant inverse association with lung cancer for smokers (HR= 0.80, 95% CI= 0.55-1.17), little association for life-long non-smokers (HR= 0.99, 95% CI= 0.45-2.21) and a non-significant positive association for ex-smokers (HR= 1.29, 95%, CI= 0.78-2.14).[28]

The association between fruit and vegetable intake and the risk of lung cancer was investigated as part of the Pooling Project of Prospective Studies of Diet and Cancer.[29] Fruit consumption was highest among never smokers and lowest among current smokers. For vegetables, intakes among never and past smokers were generally similar and exceeded intakes among current smokers. Significantly reduced risks of lung cancer were observed among those with higher total fruit (RR= 0.44, 95% CI= 0.38-0.50, *p* trend <0.001), total vegetable (RR= 0.71, 95% CI= 0.63-0.80, *p* trend <0.001) and total fruit and vegetable intakes (RR= 0.48, 95% CI= 0.43-0.54, *p* trend <0.001) on age-adjusted analysis.[29] This result was slightly weaker, although still significant when smoking status (never, past, current) was taken into account (RR total fruit= 0.66, 95% CI= 0.58-0.75, *p* trend <0.001; RR total vegetables= 0.81, 95% CI= 0.72-0.92, *p* trend 0.004; RR total fruit and vegetables= 0.67, 95% CI= 0.59-0.77, *p* trend <0.001).[29]

In 2003, a meta-analysis found that vegetable consumption appeared to provide significant protection against lung cancer (RR= 0.89, 95% CI= 0.82-0.93) with case-control studies (RR= 0.85, 95% CI= 0.77-0.92) showing a stronger protection compared to cohort studies (RR= 0.92, 95% CI= 0.84-1.07).[16] Fruit consumption also provided significant protection against lung cancer (RR= 0.85, 95% CI= 0.78-0.92).[16] This was also reflected in case-controls studies (RR= 0.83, 95% CI= 0.74-0.94) and cohort studies (RR= 0.86, 95% CI= 0.78-0.94).[16] Interestingly, fruit consumption appeared to have a significant protective effect in men that was not found in women. The results for vegetables did not differ by sex.

Bladder cancer

Fruit consumption provided significant protection against bladder cancer (RR= 0.81, 95% CI= 0.73-0.91), which was consistent across five case-control (RR= 0.82, 95% CI= 0.70-0.94) and three cohort studies (RR= 0.80, 95% CI= 0.65-0.99).[16] Vegetable consumption showed a non-significant inverse association across all studies (RR= 0.91, 95% CI= 0.82-1.00), case-control (RR= 0.90, 95% CI= 0.78-1.03) and cohort studies (RR= 0.92, 95% CI= 0.75-1.14).[16]

Summary of the evidence from epidemiology studies

Although there has been a weakening of the evidence, fruit and vegetable consumption continues to play an important role in cancer prevention. In recent reviews, fruit and vegetables have been shown to be protective against oral, laryngeal, oesophageal, colorectal and lung cancer.

The association of fruit and vegetable consumption on stomach cancer risk remains inconclusive, however fruit may possibly be protective. Fruit consumption also appears to provide protection against bladder cancer.

Fruit and vegetable consumption does not appear to be associated with a lower risk of prostate, breast or ovarian cancer. However, one meta-analysis does suggest that tomato consumption may reduce the risk of prostate cancer.

Potential mechanisms of action

Many possible mechanisms have been proposed to account for protection by fruit and vegetables, particularly as the terms “fruit” and “vegetable” include a broad range of foods, and fruit and vegetables contain a large range of biologically active compounds.

Protective dietary components include fibre, vitamins, minerals, antioxidants and phytochemicals like carotenoids, flavonoids, isoflavonoids, allium compounds and dithiolthiones.

Nutrients found in fruit and vegetables may help to lower the risk of cancer by:[30-34]

- Helping to reduce the oxidative damage to DNA caused by free radicals;
- Interacting with carcinogens e.g. reducing the formation and activation, as well as assisting with the detoxification of carcinogens; and
- Altering the activity of various metabolising enzymes and affecting cellular mechanisms important in cancer development.

A comprehensive list of the possible anti-carcinogenic mechanisms of nutrients found in fruit and vegetables can be seen in Table 4.

Table 4. Possible anti-carcinogenic mechanisms of nutrients in fruits and vegetables.[30-34]

Phytochemical	Proposed mechanism	Food Source
Vitamins C and E, carotenoids, polyphenols	Antioxidant protection against oxidative damage to DNA, cellular macromolecules and membranes.	Fruit and vegetables generally: especially yellow and orange; citrus fruit; berries.
Dithiolthiones, isothiocyanates, allium compounds	Increases Type II detoxifying enzymes (e.g. glutathione S. transferase).	Cruciferous vegetables: broccoli, cauliflower cabbage, brussel sprouts, kohlrabi; allium vegetables: onions, leeks, chives.
Vitamin C, allium compounds	Reduces bacterial formation of nitrosamines from nitrate in stomach. Decreases Type 1 activating enzymes (e.g. aryl hydroxylase).	All fruit and vegetables (Vitamin C)[35]: especially blackcurrants, guava, citrus, kiwi fruit, broccoli, sprouts; allium vegetables: onions, leeks, chives.
Folic acid	Preserve integrity of DNA and ensure optimum DNA methylation.	Green leafy vegetables; avocado; oranges.
Carotenoids, flavonoids	Induction of cell differentiation.	Yellow/orange fruits and vegetables: carrots, sweet potato, mango, pumpkin, red capsicum, rockmelon, paw paw, tomato; dark green vegetables: silverbeet, spinach, broccoli, dark green lettuce, Chinese greens (e.g. bok choy), kale, parsley, basil.
Soluble fibre, resistant starch	Decreases concentrations of secondary bile acids, which modify the enzyme activities of intestinal bacteria. Fermentation, which produces short-chain fatty	All fruits and vegetables (including legumes), particularly: Soluble fibre[36]: dried apricots, dried figs, prunes, quince, okra, cabbage, carrot, broccoli, leeks, brussel sprouts, beetroot, lychees, peas, mulberries, asparagus, lemons, oranges, swede, parsnip,

	acids that may inhibit carcinogenesis via effects on colonic pH and increased availability of butyrate.	dates, plums. Resistant starch[37]: corn, bananas, peas, potato, sweet potato, broad beans.
Insoluble fibre	Dilutes carcinogens by increasing faecal bulking. Reduces interaction of carcinogens with mucosal cells by increasing stool transit time.	All fruits and vegetables, particularly[36]: guava, quince, peas, dried figs, corn, broad beans, berries, dates, pears, prunes, cabbage, spinach , pineapple, broccoli, onion, leek, asparagus, turnip, swede, beetroot, squash, brussel sprouts, okra, carrots, pumpkin, rhubarb, green beans.

Recommendations

The Cancer Council supports the Australian Dietary Guidelines that recommend eating plenty of fruit and vegetables. Because the knowledge is still incomplete about the ways in which phytochemicals may reduce cancer risk and their potential relevance to specific tissues and to particular stages of cancer development, The Cancer Council also recommends that people eat a **variety** of different fruit and vegetables to obtain maximum benefits.

In defining the variety of fruits and vegetables to recommend, attention should be paid to their phytochemical content as well as to the epidemiological evidence concerning their protective potential. On this basis fruits should include citrus fruits, coloured fruits (especially red, yellow and orange) and berries, while vegetables should include cruciferous and allium types, dark-green leafy vegetables and red/yellow/orange vegetable types. The value of eating raw and cooked vegetables instead of taking dietary supplements has been repeatedly shown.[38] Therefore both cooked and raw vegetables should be recommended in a cancer protective diet.

The definitions for fruit in many studies include fruit juices. The cancer protective phytochemicals are preserved in fresh fruit and vegetable juices[39;40] and some phytochemicals may be more bioavailable in juices rather than whole fruits and vegetables.[41] However the fibre is removed in most vegetable and fruit juices and also in dietary supplements, and fibre is thought to be protective against colon cancer.[11;42] Therefore fruit and vegetables are best consumed whole, rather than as a juice or individual nutrients in a supplement form. As well, studies suggest that antioxidant supplements are not protective and may in fact increase overall mortality.[43]

How much fruit and vegetables should we be eating?

The population recommendation of at least **two serves of fruit** and **five serves of vegetables** daily[7;44] is appropriate for cancer prevention. For many Australians, this means doubling their current intake. Table 5 shows examples of a serve of fruit and vegetables, as specified in The Australian Guide to Healthy Eating.[44]

Table 5. Sample fruit and vegetable serving sizes in The Australian Guide to Healthy Eating.[44]

Fruit	1 serve equals:

	• 1 medium piece (150g) of fruit (apple, banana, orange, pear) • 2 small pieces (150g) of fruit (apricots, kiwifruit, plums) • 1 cup (150g) diced pieces or canned fruit • 1½ tablespoons sultanas, 4 dried apricot halves • ½ cup (125mL) fruit juice
Vegetables	1 serve equals: • ½ cup (75g) cooked vegetables • ½ cup (75g) cooked dried beans, peas or lentils • 1 cup salad vegetable • 1 small potato

As stated in the WCRF/AICR review, there is no *convincing* evidence that higher intakes of fruit and vegetables are harmful, and almost all findings are to the contrary.[8] Protection is often, but not always, found in the upper quartile or quintile of consumption, which in many studies equates approximately to the recommended 2-3 servings of fruit and 4-5 servings of vegetables.

Because some of the proposed mechanisms for how fruit and vegetables protect against cancer work at the early stages of cancer development and initiation, and most cancers develop over many years, it is important that a protective diet begins in childhood and extends into adulthood.

In addition to their anti-carcinogenic activity, fruit and vegetables play an important role in weight regulation due to their low energy density and fibre content. As obesity emerges as a major risk factor for several cancers, the importance of fruit and vegetables will continue to strengthen.

Current Australian consumption levels

The 1995 National Nutrition Survey indicated that on average, only 28% of Australians consumed at least 300g (two serves) of fruit on the day of the survey, and this included fruit juices, while only 32% ate at least 300g (four serves) of vegetables, even when potatoes were included.[45] The survey also found that nearly half of all Australian adults ate no fruit and 1 in 10 ate no vegetables on any given day.[45]

The 2006 NSW Health Survey showed that across NSW the number of people aged 16 years and over eating the recommended two serves of fruit each day had increased from 46.1% in 1997 to 53.4% in 2006, and the number eating three or more serves of vegetables each day had increased from 34.0% in 1997 to 40.9% in 2006.[46]

Research has suggested that intake of fruit and vegetables is influenced by high prices (especially of fruit), time taken to prepare vegetables, inadequate supply and quality, concerns about pesticides, and social and domestic household changes which result in less time being available to prepare food.[47] Concerns about pesticides are almost certainly unwarranted as Australian produce consistently shows low levels of chemical residues and contaminants, which are well below acceptable safety limits.[48]

Cancer survivors

There are a small number of studies indicating that diet may play a role in preventing cancer progression and recurrence in people who already have cancer, however intervention studies with cancer end-points are few in number and further research is needed before definitive dietary advice can be given to cancer patients.[49]

However the Women's Healthy Eating and Living (WHEL) study, a randomised controlled trial evaluating the effect of an increased intake of fruit, vegetables and fibre among both pre- and postmenopausal women with early-stage breast cancer, did not find a statistically significant protective association between those who increased their fruit and vegetable consumption and those who did not.[50] After an average of follow up period of 7.3 years, there were no differences in the risk of recurrence of breast cancer ($p=0.63$) or in the risk of overall mortality ($p=0.43$) between the two groups. The women in both groups of the WHEL study experienced small weight gains, so it may be possible that preventing further weight gain may have more of an impact on breast cancer recurrence and survival than just boosting fruit and vegetable intake.

The American Cancer Society have issued advice to cancer survivors, particularly of breast, lung, and colorectal cancers, to adopt the general cancer preventative recommendations for fruit and vegetables consumption, although they acknowledge there are few studies that have examined whether this improves cancer survival.[51]

Organic fruit and vegetables

Organic foods are produced without using synthetic chemicals such as pesticides, fertilisers, hormones and antibiotics or genetic modification. There is also an emphasis on appropriate land management and use of renewable resources and conservation practices. Reasons why people choose organic fruits and vegetables include reduced environmental impact, avoidance of genetic modification, better flavour and taste, perceived health benefits or just personal preference. However organic foods are more expensive than conventional foods, and there is also potentially higher wastage due to a shorter shelf life of some products.

It is difficult to measure accurately the nutritional content of organic versus conventionally grown food due to the variables that affect the end product. Such variables include types of fertilisers used, soil types, harvesting methods, transport and storage. However it appears that organic produce may provide higher levels of vitamin C and lower nitrate levels compared with conventionally produced fruits and vegetables.[52]

Presently there is no evidence to suggest that organic fruit and vegetables are more effective in reducing cancer risk than conventionally grown fruit and vegetables. Therefore the consumption of all fruits and vegetables should be encouraged, whether they are organic or not. The consumption of organic fruit and vegetables are an individual's choice. It is recommended that all fruits and vegetables be washed and peeled where appropriate to remove possible pesticide residue and possible microbial growth.

Future research

More studies are needed on the association between fruit, vegetables and cancer risk. In the future, there is a need for more studies that:

- Are prospective and include a very large follow-up period;
- Examine the reasons for differences seen between cohort and case-control study results;
- For certain cancers, investigate further the difference in risk for men and women;
- Explore the risk associated with sub-groups of fruit and vegetables e.g. citrus fruit, green leafy vegetables, cruciferous vegetables;
- Consider broad dietary patterns e.g. those that eat small amounts of fruit and vegetables may also eat small amounts of dietary fibre;
- Investigate ways in which individual phytochemicals may reduce cancer risk;
- Examine whether fruit and vegetables play a role in preventing cancer progression and recurrence in people who already have cancer; and
- Identify intermediate biomarkers that are suitable for inferring cancer outcomes or use the molecular profile of certain cancers (e.g. colorectal) as endpoints in order to help clarify inconsistent results in the literature.

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