Appendix 1

1. Natural variation of carotene and vitamin C in fruit and vegetables and contribution to dietary intake

The concentrations of certain vitamins in some fruits and vegetables may be affected by irradiation but it is important to recognise that the natural variation in vitamin content in fruits and vegetables is very large. Vitamin levels depend on the plant cultivar, growing conditions, maturity of the edible portion, post-harvest handling and storage conditions (World Health Organization 1994). On this basis, changes in the concentrations of vitamins observed in individual studies must be interpreted in the context of this variation. To this effect, a quantitative review of natural variation in the content of radiation-sensitive vitamins is provided for pome, stone, berry, citrus, tropical and other fruits, as well as cucurbit and flowering vegetables. Where appropriate, the effect of common processing techniques on carotene and vitamin C content is included.

Published data were searched using EBSCOhost. The search strategy involved searching combinations of the specific fruit or vegetable name with the following terms:

- Cultivar; storage; season; processing
- Ascorbate; ascorbic acid; vitamin C
- Carotene; carotenoid; vitamin A
- Folate
- Vitamin E or tocopherol
- Nutrient variation

Hand searching of reference lists was also used to extend publications included in the review. References and data were cross-checked with the Food Composition Database for Biodiversity developed by FAO (Stadlmayr et al. 2011).

The purpose of this section was not to provide a systematic review of all available data. Instead, the aim was to capture the extent of natural variation in nutrient composition of fruits and vegetables that is present in the published literature.

Terminology and abbreviations used in this appendix include:

- Vitamin C terms
  - AA: ascorbic acid (reduced form)
  - DHAA: dehydroascorbic acid (oxidised AA)
  - Total vitamin C: value represents both AA and DHAA.

- Vitamin A terms
    - β-carotene: pro-vitamin A carotenoid
    - β-carotene equivalents: estimated using the following formula: β-carotene (μg) + α-carotene/2 (μg) + β-cryptoxanthin/2 (μg)
    - Carotene: non-oxygenated carotenoid
    - Carotenoid: hydrocarbon pigments synthesised by plants
    - Retinol equivalents[1]: calculation of total vitamin A activity of a food. Estimated using the formula: retinol (μg) + (β-carotene/6 + α-carotene/12 + β-cryptoxanthin/12 (μg)).

- Other
    - HPLC: high pressure liquid chromatography
    - NUTTAB: nutrient tables for food available in Australia
    - USDA: nutrient tables for food in the US

1.1. Pome fruits

In Australia and New Zealand, pome fruits were not major contributors to dietary intakes of carotene or vitamin C, with the exception of vitamin C intakes in 4-8 year old boys (6% of dietary intake) and 9-13 year old girls (5% of dietary intake) in New Zealand. Pome fruit contribute 5-8% of dietary folate intake in Australian children <16 years of age, but not other population groups. Pome fruit did not contribute to >5% of dietary intakes of thiamin, riboflavin, niacin, vitamin E or B6.

As detailed in Table 1.1.1, raw apples and pears contain relatively low levels of both carotene and vitamin C, but the reported levels show a large range with up to 4-fold variation between cultivars. While the majority of pome fruits are consumed raw, a proportion of apples and pears are cooked or canned before consumption. Carotene levels tend to be higher in cooked apples, but the effect on vitamin C levels was mixed; in Australian and US food composition tables vitamin C was not detected or very low in cooked (baked or boiled) apples. In contrast, New Zealand food composition data showed 50% more vitamin C in stewed apples. The effect of canning on pears was more consistent, with vitamin A not detected, and vitamin C decreasing 66-83%. However, due to differences in the time that samples were collected and analysed, the validity of direct comparisons is limited in this case.

Published data on different apple cultivars found vitamin C level ranged from 0.4-35 mg/100 g, with lower levels in early-harvest fruit and higher levels in later-harvest fruits (Table 1.1.2) (Davey and Keulemans 2004; Vrhovsek et al. 2004; Lata 2007; Kevers et al. 2011). In the Davey study (2004), storage of apples at room temperature for 10 days led to 35% loss of

[1] For an alternate approach, calculating Retinol Activity Equivalents (RAE), please see the “DRI Essential Guide to Nutrient Requirements” (2006), available at http://www.nap.edu/openbook.php?record_id=11537&page=170

vitamin C, and cold storage (1°C) for 3 months decreased vitamin C by 23%. Greater losses were reported by Kevers (2011), with up to 75% of AA lost during 7 days storage at room temperature, and up to 90% lost with 3-9 months cold storage in either air or low oxygen atmosphere. The greater losses reported by Kevers et al. may be due to estimation of AA only, and the use of the titrimetric method of analysis. These large storage-associated losses may explain why vitamin C values in food composition tables lie at the low end of the range. For example, data for some apple varieties in Australian data tables (NUTTAB 2010) were store bought, and therefore may have undergone extended storage.

Table 1.1.1 β-carotene and vitamin C contents of raw and processed pome fruits

Fruit	β-carotene (μg/100 g)		Vitamin C (mg/100 g)		
	NUTTAB[a]	NZ	NUTTAB[a]	NZ	USDA
Apple	**0-19**	**11**	**2-6**	**8**	**5**
Apple (cooked)	*90*	*39*	*0*	*12*	*<1*
Pear	**0-20**	**0-10**	**4-6**	**3**	**4**
Pear (canned)	*0*[b]	*0-15*[c]	*1*[b]	*1*[c]	*1*[b]

[a]Where values are provided for different varieties a range is given. [b]Drained fruit canned in either juice, syrup or intense sweetened liquid. [c]Undrained fruit canned in either juice or syrup

Vitamin C content in apples also varied with season, with the effect of season being cultivar dependent (Lata 2007). While the mean and range vitamin C content was similar overall, 10 of 19 cultivars exhibited lower vitamin C levels in the 2004 season (-10 to -47%), 7 of 19 had greater levels (+9 to +46%), with the remaining two cultivars having similar vitamin C content between seasons. In addition, vitamin C content varies with fruit position within the tree; vitamin C levels were 21% lower in peel and 24% lower in flesh of shaded compared to sun exposed Gala apples (Li et al. 2009).

Vitamin C content of seven pear cultivars ranged from 5-30 mg/100 g (Silva et al. 2010; Kevers et al. 2011). Vitamin C levels decreased with fruit maturation in Conference pears, with ~3-fold reduction during on-tree maturation, and levels continued to decrease during post-harvest storage (Franck et al. 2003). At harvest, vitamin C concentration was ~6 mg/100 g, but after 3 weeks storage it decreased to 1-3 mg/100g, depending on storage conditions and remained in this range up to 7 months after harvest. Similar effects of storage and maturity were observed in Rocha pears, with minimal effect of post-harvest treatments on AA losses (Silva et al. 2010). In Conference pears, no seasonal effect was observed for vitamin C content (Franck et al. 2003).

Table 1.1.2 Summary of data from published literature on variation in vitamin C (mg/100 g) content of whole pome fruit with variety, season and storage.

Study	**Variety**	**Season**	**Storage**
31 **apple** cultivars. AA, DHAA and total vitamin C analysed at harvest, after 10 days at ambient temperature and after 3 months at 1°C. AA and DHAA by HPLC. Davey, 2004	Total vitamin C At harvest: Mean: 12.7 Range: 7.1-25.5	Not determined	Total vitamin C Ambient: Mean: 8.3 (-35%) Range: 1.9-23.1 Cold Storage: Mean: 10.3 (-19%) Range: 2.8-28.0
19 **apple** cultivars. Total vitamin C measured in 2 consecutive seasons by derivatization. Łata, 2007	See adjacent season column.	Total vitamin C Mean (range) 2004 (hot, dry): 12.0 (5.9-24.2) 2005 (hot): 11.6 (4.5-25.0)	Not determined
8 **apple** cultivars. AA measured by HPLC. Vrhovsek, 2004	AA Mean: 4.1 Range: 0.4-8.1	Not determined	Not determined
4 apple cultivars. AA by titration method. Bhusan, 1998	AA Mean: 2.6 Range: 1.5-3.3		AA 6 months, 2-4°C: Mean: 0.7 (-69%) Range: 0.4-1.5 (-30% to -89%)
14 **apple** and 6 **pear** cultivars. AA measured at harvest and after storage, with effect of season assessed in select cultivars. *Changes estimated from graphical data.* AA by titration method. Kevers, 2011	AA at harvest Apples: Mean: 23.8 Range: 11.6-35.3 Pears: Mean: 18.8 Range: 7.5-29.7	Not determined for AA, but phenolics and antioxidant capacity differed by ~15% to ~65%. No significant effect of harvest time within a season	AA in apples 7 days, 20°C: -75% 3-9 months, 1°C: -70% to -90%
Conference **pear** cultivar. Vitamin C measured during ripening and storage in air or controlled atmosphere (CA). *Changes estimated from graphical data.* AA and DHAA by HPLC. Franck, 2003	Not determined	Total vitamin C similar (Harvest season 2001 and 2002)	Total vitamin C 3 weeks post-harvest: On tree: -40% Air, -1°C: -55% CA, -1°C: -75%
Rocha **pear** cultivar. AA, DHAA and total vitamin C measured at early, optimal and late harvest, and throughout 240 days	Not determined	Not determined	Total vitamin C At harvest: 5.2-6.6 At 240d: ~4 (-20-40%) Minimal effect of

Study	Variety	Season	Storage
storage. AA by derivatization. Silva, 2008			post-harvest treatment NB: estimated from graph

In summary, there is a wide range of vitamin C levels in different pome fruit cultivars, and while some are susceptible to seasonal variations, the overall differences between seasons appears limited. In pome fruit, total vitamin C content decreases rapidly after harvest, and these storage-associated changes may underlie the relatively low values for vitamin C content for pome fruit in nutrient data tables. Carotenoid levels are low in pome fruits, with little published data available on the effects of cultivar, season and storage in these fruit.

1.2. Stone Fruit

Stone fruit were not major contributors to dietary intake of vitamin C, folate, thiamin, riboflavin, niacin, vitamin E or vitamin B6 in any of the age or gender groups studied in Australia and New Zealand. Similar results were found for carotene, with the exception of New Zealand females aged 19-29 and 50-69; in these groups stone fruit contributed to 5% of dietary carotene intake (expressed as β-carotene equivalents).

Data from food composition tables indicates a wide range in β-carotene and vitamin C content for different stone fruits (see Table 1.2.1). In canned stone fruit, carotene levels are generally similar, whereas vitamin C levels decrease >40% and in some cases by >90%. However, some of these differences, in particular in carotene levels, may be due to the different cultivars and stage of ripeness used for canned stone fruits.

Table 1.2.1 β-carotene (µg/100 g) and vitamin C (mg/100 g) contents of raw and canned stone fruits

Fruit	β-carotene		Vitamin C		
	NUTTAB[a]	NZ	NUTTAB[a]	NZ	USDA[a]
Apricot	**197**	**5170**	**12**	**7**	**10**
Apricot (canned)	*590-1750[b]*	*800[c]*	*4-5[b]*	*4[c]*	*3[d]*
Cherry	**56**	**26**	**19**	**20**	**7**
Nectarine	**65**	**362**	**12**	**4**	**5**
Peach	**147**	**477**	**9**	**10**	**7**
Peach (canned)[b]	*216-360[b]*	617[c]	*3-10[b]*	*4[c]*	*1[c]*
Plum	**147**	**417**	**5**	**3**	**10**
Plum (canned)	130[c]	479[c]	*0[c]*	*2[c]*	*<1[c]*

[a]Where values are provided for different varieties a range is given. [b]Range presented for drained fruit canned in either juice, syrup or intense sweetened liquid. [c]Drained fruit canned in heavy syrup. [d]Canned in water, solids and liquids

As detailed in Table 1.2.2, studies of vitamin C levels in stone fruit found levels vary from 1.3-fold (yellow nectarines) to >5-fold (apricots) between cultivars of the same fruit (Girard and Kopp 1998; Gil et al. 2002; Hegedüs et al. 2010). In cherries, storage was associated with decreases in AA content by up to 70-80%, with controlled atmosphere attenuating these losses (Tian et al. 2004; Akbudak et al. 2009). However, as demonstrated in a study of peaches, measurement of AA alone can be misleading. In Rojo Rito peaches, AA content decreased by 66% over 14 days ambient temperature storage, but there were concomitant increases in DHAA, with total vitamin C levels actually increasing by 10% (Flores et al. 2008).

Carotene levels also exhibit a high degree of inter-cultivar variability, with apricots showing >10-fold difference between cultivars (Ruiz et al. 2005; Flores et al. 2008), and levels varying 1.4 to 3.3-fold in cherry, nectarine, peach and plum cultivars (See Table 1.2.2) (Girard and Kopp 1998; Gil et al. 2002; Di Vaio et al. 2008). In plums, AA and total carotenoid levels increased with ripening and 3-weeks storage, but levels for both nutrients decreased after 6-weeks (Khan et al. 2009). In Rojo Rito peaches, carotenoid levels increased ~60% during 14 days storage at ambient temperature (Flores et al. 2008). Similarly, β carotene and other carotenoids increased ~2-fold with 8 days ambient temperature storage in Spring Belle peaches (Caprioli et al. 2009). β-carotene levels also increased in apricots during 14 days cold storage, with levels 27-57% higher than harvest levels (Leccese et al. 2010).

Table 1.2.2 Natural variation and effects of season and storage on carotene (μg/100 g) and vitamin C (mg/100 g) levels in whole stone fruit[1].

Study	Variety	Season / Growing conditions	Storage
15 **apricot** genotypes. Vitamin C (not specified) by HPLC method. Hegedus, 2010	Vitamin C Mean: 8.5 Range: 3.0-16.2	Not determined	Not determined
37 **apricot** varieties, including white, yellow, light orange and orange-fleshed varieties. Carotenoids by HPLC. Ruiz, 2005	Total carotenoid Mean: 6627 Range: 1512-16500	Not determined	Not determined
29 **apricot** cultivars and hybrids. Total carotenoids measured spectrophotometrically. Drogoudi, 2008	Total carotenoid Mean: 2320 Range: 950-3780	Not determined	Not determined
5 **apricot** cultivars grown under integrated and organic systems at harvest and after 7 and 14 days cold storage. Carotene data presented for 2 varieties measured by HPLC . Leccese, 2010	β-carotene at harvest in integrated apricots: Cafona: 1153 Pellecchiella: 1680	β-carotene at harvest in organic apricots: Cafona: 799 (-31%) Pellecchiella: 2218 (+24%)	β-carotene Integrated (7d: 14d): Cafona: 1154: 1560 (+35%) Pellecchiella: 1840: 2505 (+49%) Organic (7d: 14d): Cafona: 915: 1261 (+57%) Pellecchiella: 2009: 2807 (+27%)
12 **cherry** cultivars. AA by HPLC Girard, 1998	AA Mean: 12.7 Range: 8.4-17.6	Not determined	Not determined
Storage of '0900 Ziraat' **cherry** for 30 and 60 days at 0°C, and 60 days at 0°C followed by 2 days at 20°C with controlled atmosphere (CA). Spectrophotometric determination of AA. Akbudak, 2009	AA At harvest: 24.5	Not determined	AA Normal air: 30d: 12.7 (-48%) 60d: 10.1 (-59%) 60+2d: 7.3 (-70%) CA (25% CO_2:5% O_2): 30d: 19.8 (-19%) 60d: 17.0 (-31%) 60+2d: 13.4 (-45%)
5 cultivars for white and yellow **peaches** (WP, YP), white and yellow **nectarines** (WN, YN) and **plums** (25 total). AA, DHAA and total carotenoids measured 5 days after harvest by HPLC. Gil, 2002	Total vitamin C mean (range): WP: 7.1 (5.9-8.6) YP: 8.0 (3.8-13.3) WN: 9.5 (5.1-13.9) YN: 6.4 (5.9-7.2) Plum: 6.1 (2.6-10.7) Total Carotenoids WP: 12 (8-18) YP: 139 (100-207)	Not determined	Not determined

Study	Variety	Season / Growing conditions	Storage
	WN: 10 (8-12) YN: 135 (91-171) Plum: 135 (87-285)		
7 yellow **peach** cultivars and 5 yellow **nectarine** cultivars and 1 white nectarine cultivar. β-carotene measured at harvest and after 7 days cold storage by HPLC. Di Vaio, 2008	<u>β-carotene</u> Yellow peach: Mean: 48 Range: 38-62 Yellow nectarine: Mean: 32 Range: 26-37 White nectarine: 12	Not determined	<u>β-carotene</u> Peach: Mean: 45 (-7%) Range: 34-61 Nectarine: Mean: 31 (-1%) Range: 27-36 White nectarine: 9 (-27%)
Rojo Rito **peaches** stored for 14 days at 20° in the presence or absence of nitric oxide (NO) gas. AA and DHAA by HPLC analysis, total carotenoids by spectrophotometry. Flores, 2008	AA: 10.5 DHAA: 4.4 Total vitamin C: 14.9 Carotenoids: 2790		<u>AA</u> Air: 3.6 (-66%) NO: 5.1 (-51%) <u>DHAA</u> Air: 8.0 (+82%) NO: 7.8 (+77%) <u>Total vitamin C</u> Air: 11.6 (+10%) NO: 12.9 (+23%) <u>Carotenoids</u> Air: 4440 (+60%) NO: 4480 (+61%)

[1]Studies summarised in this table are restricted to those where numerical data were presented in the publications

In summary, there is a wide range of vitamin C and carotene levels in stone fruit, as reported in nutrient data tables and published literature. AA content is susceptible to decreases with processing and storage, but it is important to consider conversion of AA to DHAA when considering these effects on total vitamin C. In contrast to vitamin C, carotene levels were generally unaffected or increased with processing and storage of stone fruits.

1.3. Berry fruit

Berries are a rich source of vitamin C, but despite this berries did not contribute >5% of dietary vitamin C intake. Similarly, berries did not constitute a major contributor to carotene, folate, thiamin, riboflavin, niacin, vitamin E or vitamin B6 intakes in any of the age or gender groups studied in Australia and New Zealand.

As detailed in Table 1.3.1, there is a large range in carotene and vitamin C levels between different berry types and in levels reported from different countries. Berries are commonly canned or frozen, with both these processes impacting on nutrient levels. Carotene is relatively stable during these processes, with the exception of an 85% decrease in canned blueberries in Australian data. In contrast, vitamin C is generally lower in frozen berries (mean; -29%, range; -30% to -86%), with larger losses occurring in canned berries (mean; -76%, range; -46% to -90%). As for stone fruit, some caution needs to be applied in making direct comparisons between fresh and frozen or canned berries, as the effects of season, growing location and cultivar may also influence nutrient composition.

Table 1.3.1 β-carotene and vitamin C (mg/100 g) levels of fresh, frozen and canned berries.

Fruit	β-carotene (μg/100 g)		Vitamin C (mg/100 g)		
	NUTTAB[a]	NZ	NUTTAB[a]	NZ	USDA[a]
Blackberry	**150**	**76**	**38**	**20**	**21**
Blackberry (canned)	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*3[c]*
Blueberry	**39**	**8**	**13**	**4**	**10**
Blueberry (canned)	*20[b]*	*n.a.*	*2[b]*	*n.a.*	*<1[b]*
Blueberry (frozen)	*38*	*15*	*9*	*6*	*3*
Raspberry	**28**	**0**	**32**	**14**	**26**
Raspberry (canned)	*0[b]*	*n.a.*	*5[b]*	*n.a.*	*9[c]*
Raspberry (frozen)	*26*	*n.a.*	*22*	*n.a.*	*17*
Strawberry	**0**	**6**	**45**	**46**	**59**
Strawberry (canned)	*11[b]*	*n.a.*	*12[b]*	*n.a.*	*32[c]*
Strawberry (frozen)	*0*	*n.a.*	*32*	*n.a.*	*41*

[b]Drained fruit canned in syrup. [c]Undrained fruit canned in syrup

Studies of strawberry cultivars demonstrate a strong effect of genotype on vitamin C levels, with content ranging from 23-185 mg/100 g in different cultivars (Table 1.3.2) (Shin et al. 2008; Tulipani et al. 2008; Josuttis et al. 2012; Pincemail et al. 2012). In two studies of 3 and 12 cultivars, mean AA contents were 70 and 106 mg/100 g, respectively (Josuttis et al. 2012; Pincemail et al. 2012). These values are higher than those reported in nutrient data tables for Australia, New Zealand and the US, but the values in these tables still fall within the range reported in published literature. Vitamin C content in strawberries also varied with harvest time, season, location and growing conditions (Josuttis et al. 2012; Pincemail et al. 2012).

Table 1.3.2 Natural variation and effects of season and storage on vitamin C (mg/100 g) levels in berry fruits.

Study	Variety	Season / Growing conditions	Storage
6 **blackberry** cultivars.	AA	Not determined	Not determined

Study	**Variety**	**Season / Growing conditions**	**Storage**
AA and DHAA by titration following solid phase extraction. Thomas, 2005	Mean: 9.1 Range: 8.3-10.3 <u>DHAA</u> Mean: 1.1 Range: 0.2-2.9 <u>Total Vitamin C</u> Mean: 10.1 Range: 8.4-11.9		
13 **raspberry** cultivars and 2 experimental genotypes harvested from 3 growing sites in 3 consecutive years. AA by LC-MS Pirogovskaia, 2012	<u>AA</u> (12 cultivars) Mean: 20.9 Range: 7.0-40.6	<u>AA</u> Season: Mean (range) 2008: 13.7 (7.0-24.5) 2009: 23.4 (11.3-40.6) 2010: 25.6 (14.6-34.1) Site: Genotype 36: 27.1-35.3 C. Delight: 20.5-21.6 Malahat: 23.1-37.6	Not determined
11 wild **raspberry** genotypes and 1 commercial cultivar harvested over 2 years. AA by commercial assay Tosun, 2009	<u>AA</u> Mean: 28 Range: 21-36	No significant effect of year (data not shown): pooled data presented	Not determined
4 **raspberry** cultivars. Assessed at harvest, after 1 day at 20°C and after 3 days at 2-4°C + 1 day at 20°C. AA by titration. Krüger, 2011	<u>AA</u> Mean: 29.0 Range: 18.3-33.3	Not determined	<u>AA</u> 1d: 28.7 3+1d: 28.3 *Not significant*
5 commercial **strawberry** cultivars and 4 experimental genotypes. AA by HPLC. Tulipani, 2008	<u>AA</u> Range: 23-47	Not determined	Not determined
3 **strawberry** cultivars, 4 locations and 2 consecutive years. AA by titration. Josuttis, 2012	<u>AA</u> Mean: 70.1 Range: 36.5-98.0	<u>AA</u> Season: Mean (range) 2008: 64.8 (36.5-88.7) 2009: 74.2 (46.8-98.0) Site: Range (no. of sites) Elsanta: 74.2-91.6 (4) Korona: 50.8-57.8 (3) Clery: 65.2-80.0 (2)	Not determined
12 **strawberry** cultivars grown under various conditions and harvested	<u>AA</u> Mean: 105.9 Range: 51.0-184.7	<u>AA</u> Elsanta cv., different growing conditions	Not determined

Study	Variety	Season / Growing conditions	Storage
(1) at various times within a growing season ad (2) in 2 consecutive years. AA by titration. Pincemail, 2012		May-Nov harvest: Mean: 75.2 Range: 33.7-115.5 Significant effect of year (graphical data)	
2 **strawberry** cultivars stored at 3°C for 1-20 days in either air or 20% CO_2. Total vitamin C, AA, and DHAA by enzyme assay. Shin, 2008	At harvest: <u>AA</u> Northeaster: 32.3 Earliglow: 44.9 <u>DHAA</u> Northeaster: 0.5 Earliglow: 0 <u>Total vitamin C</u> Northeaster: 32.8 Earliglow: 44.9	Not determined	Day 20, Northeaster: <u>AA</u> Air: 44.2 (+27%) CO_2: 28.6 (-11%) <u>DHAA</u> Air: 0 CO_2: 1.7 (+250%) <u>Total vitamin C</u> Air: 42.0* CO_2: 30.3 (-8%) Day 20, Earliglow: <u>AA</u> Air: 52.4 (+17%) CO_2: 24.2 (-46%) <u>DHAA</u> Air: 3.9 CO_2: 13.9 <u>Total vitamin C</u> Air: 56.3 (+25%) CO_2: 38.1 (-15%) **Total vitamin C value as reported in paper is lower than AA value*

Published data on raspberry vitamin C content reported a range from 7-41 mg/100 g between cultivars: the values in nutrient data tables fall within this range (Tosun et al. 2009; Pirogovskaia et al. 2012). AA content was also influenced by growing site and was significantly different between seasons, with levels varying up to 1.9-fold between years (Pirogovskaia et al. 2012). A study of blackberry cultivars reported a range in Total vitamin C from 8-12 mg/100g; these values are ~3-fold lower than values reported in the nutrient data tables (Thomas et al. 2005).

A study on nutrient stability in different berry fruits over 8 days at temperatures between 0-30°C showed vitamin C levels were relatively stable in strawberries and highbush blueberries (Kalt et al. 1999). In contrast, vitamin C levels decreased by 22% and 46% in raspberries at 20° and 30°C respectively. There was also a significant, albeit small, decline in vitamin C levels with storage at higher temperatures in lowbush blueberries. In other studies of raspberries, vitamin C and anthocyanin content was stable over 3-4 days storage, and also with freezing (Mullen et al. 2002; Krüger et al. 2011). In contrast, a study of raspberries stored for 9 days in either controlled atmosphere or high CO_2 at 1°C reported total vitamin C declined by 90% (Agar et al. 1997; Mullen et al. 2002). In strawberries, there was a significant effect of atmosphere on Total vitamin C levels during storage; levels increased 28-29% in air, but decreased by 8-13% in 20% CO_2 over 20 days (Shin et al. 2008). Similarly, total vitamin C levels were stable in strawberries stored in controlled atmosphere or high CO_2 at 1°C for 20 days, but the proportion of DHAA increased from ~10% to ~50-75% in strawberries stored in 20% CO_2 (Agar et al. 1997). In the same study, further storage in controlled atmosphere and removal of berries to ambient conditions to mimic shelf-life resulted in higher levels of DHAA, and also loss of total vitamin C (approximately -30% from day 0). In blackberries, total vitamin C levels were stable over 9 days storage, but there was an increase in DHAA levels (Agar et al. 1997).

In summary, vitamin C levels vary up 8-fold between berry cultivars, and are also affected by growing season and location. Vitamin C levels are relatively stable in berries during short-term storage, but the proportion of DHAA rose during storage. Prolonged storage was associated with losses of total vitamin C. Large losses of vitamin C occur in frozen berries, with even greater losses in canned berries.

1.4. Citrus fruit

Citrus fruit are a major dietary contributor to vitamin C in all age and gender groups in Australia and New Zealand, with the exception of 17-18 year old Australian females. Citrus fruit provide 5-17% of vitamin C intake. Citrus are not a major source of dietary carotene, thiamin, riboflavin, niacin, folate or vitamins E and B6 in Australia and New Zealand.

Vitamin A and C contents of different citrus fruits, as reported in nutrient composition tables for Australia, New Zealand and the USA, are summarised in Table 1.4.1. These data indicate a large range of carotene and vitamin C content between citrus fruit types, and between cultivars of different citrus fruits. However, vitamin C levels are consistently high across all citrus types.

Table 1.4.1 β-carotene (µg/100 g) and C (mg/100 g) levels in citrus fruits from nutrient reference tables

Fruit	β-carotene		Vitamin C		
	NUTTAB[a]	NZ	NUTTAB[a]	NZ	USDA[a]
Grapefruit	11	0	40	40	31-79
Lemon	10	7	48	52	53
Lime	30	NA	47	na	29

Fruit	β-carotene		Vitamin C		
	NUTTAB[a]	NZ	NUTTAB[a]	NZ	USDA[a]
Mandarin	46-290	67	28-58	42	27
Orange	56-140	85	44-58	36	45-59

[a]Where values are provided for different varieties a range is given. na, data not available

As summarised in table 1.4.2, data on vitamin C levels in citrus fruits from published scientific literature are generally consistent with the values reported in the nutrient reference tables (Ladaniya et al. 2003; Dhuique-Mayer et al. 2005; Erkan et al. 2005; González-Molina et al. 2008; Milella et al. 2011; Bermejo and Cano 2012). There is a strong effect of cultivar (genotype) on vitamin C levels, with a 1.4-fold range in oranges and 2.1- to 4.6- fold differences within mandarin and clementine varieties (Dhuique-Mayer et al. 2005; Milella et al. 2011; Bermejo and Cano 2012). AA levels decreased by 22-31% over 3-6 months storage, but as DHAA levels were not reported in these studies it is unclear if these losses are representative of changes in total vitamin C (Ladaniya et al. 2003; Erkan et al. 2005).

The comparison of carotene levels between published data and nutrient reference tables is complicated by the varied units in which carotenes are reported (for example as β-carotene, total carotenoids or retinol equivalents). However, similar levels of carotene were observed in the juice of 8 orange cultivars (13-38 µg RE/100 mL), but higher levels were observed for mandarins (96-115 µg RE/100 mL) in comparison to nutrient reference tables (Dhuique-Mayer et al. 2005). Similar variations in carotenoids content for oranges and mandarins were reported by another two studies (see Table 1.4.2; (Fanciullino et al. 2008; Dhuique-Mayer et al. 2009)).

Table 1.4.2 Natural variation and effects of season and storage on carotene (μg/100 g, or as indicated) and vitamin C (mg/100 g) levels in citrus fruits.

Study	**Variety**	**Season / Growing conditions**	**Storage**
8 **orange** cultivars, 1 **mandarin** and 1 **clementine**. Carotenoids and total vitamin C by HPLC. Dhuique-Mayer, 2005	<u>Total vitamin C</u> Orange: Mean: 55.3 Range: 46.2-62.7 Mandarin: 41.3 Clementine: 53.1 <u>Vitamin A</u> (μg RE/100 mL) Orange: Mean: 24.3 Range: 13.2-38.1 Mandarin: 115.4 Clementine: 96.0	Not determined	Not determined
3 **orange** cultivars, 2 **mandarin** and 1 **clementine**. Carotenoids measured in 2-5 growing locations, and oranges assessed in 3 consecutive years. Carotenoids by HPLC. Dhuique-Mayer, 2009	<u>β-carotene</u> mg/100 mL Orange: Mean: 3.7 Range: 0.8-6.9 Mandarin Mean: 11.6 Range: 4.0-19.8	<u>β-carotene</u> Mean (range) over 3 seasons: Valenica: 4.6 (3.5-5.5) Sanguinelli: 4.3 (3.8-5.4) Pera: 5.0 (3.6-6.9) Growing location (no.): Valenica (5): 2.0 (0.8-4.8) Sanguinelli (2): 1.0-3.7 Pera (2): 2.6-6.8 Mandarin (2): 4.0-19.8 Hansen mandarin (3): 11.4 (7.0-19.7) Clementine (2): 1.7-6.8	Not determined
6 **mandarin**, 3 **hybrid**, 3 **orange**, 2 **grapefruit**, 2 **pummelo**, 2 **lime**, 1 **citron** and 1 **lemon** cultivars on different rootstocks, harvested up to 11 times between September and March. Total vitamin C by HPLC *Subset of data for single time point assessed* Bermejo, 2012	<u>Total vitamin C*</u> mean (range if>2 cultivars) Mandarin: 40.2 (25.9-54.8) Hybrid: 31.0 (16.9-55.9) Orange: 56.9 (53.1-60.2) Grapefruit: 48.0 Pummelo: 53.1 Lime: 29.6 Citron: 33.4 Lemon: 58.9	Effect of Rootstock: 9 cultivars studied. Significant effect at all 5 harvest dates for lemon and citron, and 1-2 harvest dates for 5 citrus See text for more details.	Not determined
4 **orange** cultivars. Total carotenoids by	<u>Total carotenoids</u> (mg/100 mL)	Not determined	Not determined

Study	Variety	Season / Growing conditions	Storage
HPLC Fanciullino, 2008	Mean: 2.7 Range: 0.3-4.7		
2 Fino **lemon** clones (49-5, 95) harvested at 3 sampling times over 3 consecutive years. AA and DHAA by HPLC Gonzalez-Molina, 2008	Total vitamin C Range: Clone 49-5: 21.6-40.1 Clone 95: 21.9-35.1	Total vitamin C Clone 49-5 / 95 Year: 2004: 39.5 / 30.6 2005: 30.9 / 30.1 2006: 24.2 / 24.0 Harvest time: Early: 34.9 / 29.9 Mid:26.3 / 25.3 Late: 29.0 / 27.7	Not determined
13 **clementine** cultivar and 2 hybrids. Vitamin C (not specified) by HPLC Milella, 2011	Vitamin C Mean: 57.4 Range: 20.6-95.5	Not determined	Not determined
Valencia **oranges**, stored up to 6 months following no treatment, curing at 48-53°C, or hot-water dipping. AA by titration. Erkan, 2005	AA At harvest: 60.3	Not determined	AA 6 months: Control: 44.3 (-27%) Curing: 44.4-46.9 (-22% to -26%) Hot water: 43.2-46.7 (-22% to -27%)
Lime, **mandarin** and **orange** stored for 75 (mandarin) to 90 (lime and orange) days at 6-8°C. AA by titration Ladaniya, 2003	AA At harvest: Lime: 31.8 Mandarin: 24.2 Orange: 40.4	Not determined	AA After 75-90d storage: Lime: 32.2 Mand.: 22.1 (-9%) Orange: 27.9 (-31%)

Effects of season and harvest time on vitamin C and carotene levels have also been assessed in citrus fruits. In two clones of Fino lemons, total vitamin C ranged from 24-40 and 24-31 mg/100 g over three harvest seasons, despite similar climatic conditions (González-Molina et al. 2008). In the same study, total vitamin C levels also fluctuated with harvest time, with lowest levels in mid-season harvest fruit. Similar observations were made for β-carotene levels in orange cultivars harvested in three consecutive years, with 1.4- to 1.9- fold differences between levels within the same cultivar (Dhuique-Mayer et al. 2009). The effect of growing location was also assessed in this study. β-carotene levels varied up to 6-fold between fruit of the same cultivar grown in different locations in the same year.

In a study of 9 citrus cultivars there was a variable effect of rootstock on total vitamin C levels. In the citron and lemon cultivars studied, total vitamin C content varied 12-33% and 9-21%, respectively, between fruit from the same cultivar grown on two different rootstocks and harvested at 5 intervals. In other citrus fruit, rootstock had less of an effect on vitamin C levels, with either no difference, or differences at only 1 or 2 of the time-points assessed (Bermejo and Cano 2012).

In summary, these data demonstrate that there is a high level of variation in both carotene and vitamin C content in citrus fruits, with the greatest variation coming from cultivar type. Growing season, location and harvest time also influence nutrient composition of citrus fruits. Post-harvest treatments and storage were also associated with vitamin C losses, although the susceptibility to these changes varied with fruit type.

1.5. Tropical fruit

Tropical fruits do not contribute more that 5% of dietary carotene intake in Australia and New Zealand. In contrast, 5-6% of dietary vitamin C intake in females over 50 and Australian males over 70 is derived from tropical fruits. Tropical fruits contribute 5-19% of vitamin B6 levels in the majority of population groups, except 14-18 year old Australians, 9-13 year old male Australians and female 14 year old New Zealanders. The major fruit contributing to this intake of vitamin B6 is bananas. Tropical fruits do not contribute to >5% dietary intake of thiamin, riboflavin, niacin, folate or vitamin E.

Table 1.5.1 β-carotene (µg/100 g) and vitamin C (mg/100 g) levels in tropical fruits from nutrient reference tables

Fruit	β-carotene		Vitamin C		
	NUTTAB[a]	NZ	NUTTAB[a]	NZ	USDA[a]
Avocado	20-29	50	6-13	7	9-17
Banana	23-35	75	4-19	8	9
Custard apple	0	n.a.	43	n.a.	19
Guava	380	n.a.	243	n.a.	228
Litchi	0	n.a.	49	n.a.	72
Mango	1433	1200	26	30	36
Pawpaw (papaya)	240	n.a.	60	n.a.	61
Pineapple	10	60	17	25	17-56
Pineapple (canned)	*15-17*[b]	*15-22*[b]	*8-12*[b]	*10-14*[b]	*7-10*[c]
Rambutan	0	n.a.	70	n.a.	n.a.

[a]Where values are provided for different varieties a range is given. [b]Fruit canned in syrup or juice, drained, [c]Fruit canned in syrup or juice, solids and liquids

Nutrient composition data for tropical fruits are presented in Table 1.5.1. Avocados are lipid-rich, and show a high level of variability in both carotene and vitamin C between cultivars. In Hass avocados, β-carotene levels varied from 10-100 μg/100 g in fruit depending on growing location and harvest time (Lu et al. 2009).

Bananas also exhibit variation in vitamin content; one report found total provitamin A carotenoids varied 20% within individual fruits, and further variation of ±7% to ±43% occurred within the hand of bananas from different varieties. Total provitamin A carotenoid content ranged from 3-76 nmol/g dry weight (i.e. 161-4080 μg/100 g) between six banana and plantain varieties (Davey et al. 2007; Lu et al. 2009). In another study of two banana cultivars, β-carotene content ranged from 43-131 μg/100 g, and vitamin C from 3-18 mg/100 g (Wall 2006a). In Southeast Asia there are a number of banana cultivars with orange to red coloured flesh, with β-carotene levels of up to 1370 μg/100 g in these banana cultivars (Englberger et al. 2003).

A study of 5 mango varieties reported a range of mean β-carotene levels from 500-2600 μg/100 g between varieties, with intra-variety variations of 1.4 to 7.0-fold depending on location and harvest time (Manthey and Perkins-Veazie 2009). Vitamin C levels ranged from 12-125 mg/100g between varieties, and the intra-variety variation ranged from 1.1 to 2.6-fold. In a study on the effects of fruit handling on β-carotene and vitamin C levels in mango and papaya, the effect of fruit-to-fruit variation was greater than that of handling, particularly for vitamin C (standard deviation was >40% of mean) (Oliveira et al. 2010). In green mangoes, vitamin C levels decreased 50% and 58% over 15 days in whole and fresh-cut fruit, respectively (Robles-Sánchez et al. 2009). Losses of β-carotene were similar in fresh-cut fruit (-40%), but levels were stable in whole-fruit over 15 days.

Nutrient composition varied between two pineapple varieties; β-carotene, total carotenoids and total vitamin C content were 2.4-, 3.0- and 1.9-fold higher, respectively, in Del Monte Hawaii Gold compared to Smooth Cayenne pineapples (Ramsaroop and Saulo 2007). Vitamin C and total phenol content also varied within pineapple, with highest levels in the middle third of fruits, and levels 8-13% lower in the top third and 10-21% lower in the bottom third of the fruit (Montero-Calderón et al. 2010). Pineapples are commonly canned, and this process can decrease vitamin C content by >30% (see Table 1.5.1).

Table 1.5.2 Natural variation and effects of season and storage on carotene (µg/100 g, or as indicated) and vitamin C (mg/100 g) levels in tropical fruits.

Study	Variety	Season / Growing conditions	Storage
Hass **avocado** grown in 4 locations and harvested at 4 times. Carotenoids by HPLC. Lu, 2009	Not determined	β-carotene Effect of location: Mean (range) January: 26 (10-41) April: 65 (56-78) July: 79 (58-88) September: 69 (52-101) Total carotenoids Range: 590-4220	Not determined
2 **banana** and 5 **papaya** cultivars grown in 2-7 locations. AA and carotene (µg RE/100 g) by HPLC Wall, 2006a	AA Mean (range): Banana: 9.7 (4.5-12.7) Papaya: 51.2 (45.3-55.6) RE Banana: 10.9 (8.2-12.4) Papaya: 44.1 (20.4-50.3)	AA Banana: Dwarf: 6.3-17.5 Williams: 2.5-6.3 Papaya: Rainbow: 46.6-60.4 Sunrise: 46.8-64.5 RE Banana: Dwarf: 7.7-17.1 Williams: 6.1-9.3 Papaya: Rainbow: 32.0-74.0 Sunrise: 18.7-72.5	Not determined
6 **banana/plantain** cultivars assessed in fruit from 1-3 plants. Pro-vitamin A carotenoids (pVAC) by HPLC Davey, 2007	pVAC (nmol/g dry weight) Mean: 36.7 Range: 2.7-76.3	Not determined	Not determined
Guava grown in 3 locations. AA by HPLC. Gull, 2012	Not determined	AA Mean: 175.7 Range: 129.5-247.9	Not determined
2 **longan**, 3 **litchi** and 6 **rambutan** cultivars harvested from 3-5 locations. AA by HPLC. Wall, 2006b	AA Mean (range): Longan: 60.1 (44.7-79.2) Litchi: 27.6 (21.0-36.0) Rambutan: 36.4 (22.0-47.8)	AA Range for cultivars grown in ≥1 location Longan: Biew Kiew: 44.7-79.2 Sri Chompo: 51.2-59.0 Litchi: Bosworth: 21.0-24.0 Kaimana: 30.7-36.0 Rambutan: Rongrien: 37.6-39.3	Not determined

Study	Variety	Season / Growing conditions	Storage
5 **mango** cultivars, 1-4 growing locations and 1-4 harvests within a season for each location. AA measured spectrophotometrically, and β-carotene by HPLC. Manthey, 2009	<u>AA</u> Mean: 37.8 Range: 11.5-134.5 <u>β-carotene</u> Mean: 1160 Range: 310-3900	Growing location by cultivar <u>AA</u> Tommy Atkins: 17.0-20.3 Haden: 27.5-31.7 Kent: 22.6-27.4 <u>β-carotene</u> Tommy Atkins: 450-580 Haden: 490-810 Kent: 840-2180	Not determined
9 cultivars of Thai **mango**, 4-7 days post-harvest ripening, 2 consecutive years. Carotene (μg RE/100g dry weight) by HPLC. Vasquez-Caicedo, 2005	<u>RE</u> Mean: 1037 Range: 281-2049	<u>RE</u> Season: Mean (range) 2001: 1061 (281-1573) 2002: 1013 (397-2049) Difference by cultivar: 0.5 to 1.6-fold	Carotene increase up to 8.8-fold with ripening
2 **pineapple** cultivars Total vitamin C and carotene by HPLC Ramsaroop, 2007	<u>Total vitamin C</u> Range: 35-68 <u>β-carotene</u> Range: 17.2-41.6	Not determined	Not determined
Within-fruit variation in vitamin C of **pineapple**. Total vitamin C by HPLC Montero-Calderon, 2010	<u>Total vitamin C</u> Upper third: 30.5 Middle third: 35.1 Bottom third: 33.3	Not determined	Not determined

A study of papaya cultivars in Hawaii found β-carotene ranged from 81-410 μg/100 g, and vitamin C ranged from 45-65 mg/100 g (Wall 2006a). In litchi, vitamin C content varied from 21-36 mg/100g, depending on cultivar and location (Wall 2006b). Storage of litchi was associated with rapid decline in AA content, with ~40% decrease after 8 days storage at ambient temperature, and losses of approximately 35% during 8 weeks cold storage (Mahajan and Goswami 2004). Similar losses were observed in two other litchi cultivars, with 40-45% decrease in AA during 28 days cold storage (Khan et al. 2012). Vitamin C was also variable in rambutans, with levels ranging from 22-48 mg/100 g (Wall 2006b). In guava, vitamin C content increased with fruit ripeness, and also varied with geographic growing location; vitamin C content in unripe fruit ranged from 73-136 mg/100 g, and in ripe fruit from 129-248 mg/100 g (Gull et al. 2012).

In summary, the tropical fruit category encompasses a wide variety of fruits, with some rich in either vitamin C, carotene or both. Across all fruit types, there is a large variation in nutrient composition with cultivar, and for the fruits where data were available it was evident that harvest time and location also effect vitamin C and carotene content. Vitamin C levels decline rapidly with storage in mango and litchi, but carotene levels increased with ripening in stored mangos.

1.6. Other fruit

Grapes, rockmelon (cantaloupe), honeydew melon, watermelon, kiwifruit and persimmon are included in “other fruit” in the Australian and New Zealand nutrition surveys. The other fruit category contributed to 7% and 5% of dietary carotene intake in Australian male children aged 2-3 and 4-8 years old, respectively. For vitamin C, other fruit contributed 5-6% of dietary intake in Australian 2-3 year olds and female 4-8 year olds. In New Zealand, other fruit made a major contribution to vitamin C intake in females aged 14 years (7%), 50-69 years (6%) and ≥70 years (9%).

As summarised in Table 1.6.1, yellow-fleshed kiwifruit tend to have higher vitamin C content in comparison to green-fleshed species. A study of kiwifruit species and cultivars found total vitamin C content ranged from 26-185 mg/100 g in green-fleshed fruit. The most commonly consumed kiwifruit cultivar is Hayward, and the inter-fruit variation in vitamin C content in this cultivar was 26%, with a mean concentration of 55 mg/100 g (Nishiyama et al. 2004). Vitamin C content is still dependent on cultivar in yellow-fleshed kiwifruit, with concentrations ranging from 64-206 mg/100 g (Table 1.6.2, (Nishiyama et al. 2004)). During storage, AA levels decreased with time, with 32% reduction between 1 and 5 months (Aghdam et al. 2011). Treatment with methyl salicylate decreased the storage-associated diminution of AA. However, without DHAA or total vitamin C data it is unclear whether these changes represent destruction or conversion of AA.

As shown in Table 1.6.1, there is a large range in carotene and vitamin C content in grapes. The range of β-carotene levels in black grapes was 40-91 µg/100 g, with +9 to -38% variation in β-carotene levels observed between two consecutive seasons (Oliveira et al. 2004). The same study also showed that β-carotene levels were higher in shaded fruit, in fruit grown at a greater plant height and that levels decreased with ripening.

Table 1.6.1 β-carotene (μg/100 g) and C (mg/100 g) levels in grapes, kiwifruit, persimmon and watermelon.

Fruit	β-carotene		Vitamin C		
	NUTTAB[a]	NZ	NUTTAB[a]	NZ	USDA
Grape	0-50	54-91	0-7	4	3
Honeydew melon	30-50	30	12-20	50	18
Kiwifruit (gold)	45	43	110	109	105
Kiwifruit (green)	50	54	71	85	93
Passionfruit	360	10	18	20	30
Persimmon	200	825	14	10	8
Rockmelon	836	205	41	27	37
Watermelon	427	20	8	8	8

[a]Where values are provided for different varieties a range is given.

Published data for carotene in Chinese-grown persimmons is lower than that in nutrient data tables, with levels ranging 12-91 μg RE/100 g in astringent cultivars, and 9-35 μg RE/100 g in non-astringent cultivars (Zhou et al. 2011). Published values for vitamin C content of persimmon (8-14 mg/100 g) were similar to the values in the nutrient data tables (12 mg/100g) (Celik and Ercisli 2008).

β-carotene levels vary 2-10-fold between watermelon cultivars (Perkins-Veazie et al. 2006; Tlili et al. 2011a). Vitamin C levels also varied between watermelon cultivars, with levels varying from 11-34 mg/100 g in ripe fruit (Tlili et al. 2011a; Tlili et al. 2011b). The vitamin C content also varies within watermelon, with the distribution of AA and DHAA within fruit varying with cultivar (Tlili et al. 2011b).

Honeydew melon and rockmelon are cultivars of muskmelon. As detailed in Table 1.6.1 there is a wide range of carotene and vitamin C content as reported in nutrient composition tables. In a study of recombinant inbred lines of melon, β-carotene levels varied between lines and were also affected by growing location and season (Cuevas et al. 2008). Overall, β-carotene levels ranged from 330-2440 μg/100 g. Another study compared standard, hybrid and grafted melons and found AA levels ranged from 5-22 mg/100 g (Kolayli et al. 2010). In a study of four honeydew melon cultivars, total vitamin C levels ranged from ~13-26 mg/100 g, with up to 3-fold variation in vitamin C levels between fruit harvested in 2 consecutive years (Lester and Crosby 2002).

Table 1.6.2 Natural variation and effects of season and storage on carotene (μg/100 g) and vitamin C (mg/100 g) levels in grape, melon, kiwifruit and persimmon.

Study	**Variety**	**Season / Growing conditions**	**Storage**
8 **grape** cultivars harvested in 2 consecutive seasons. β-carotene by HPLC. Oliveira, 2004	β-carotene Mean: 59.8 Range: 40.2-91.0	β-carotene Mean (range) 2001: 66.2 (45.6-91.0) 2002: 53.3 (40.2-62.1)	Not determined
21 **kiwifruit** cultivars; 14 green-fleshed and 7 yellow-fleshed. Total vitamin C by HPLC. Nishiyama, 2004	Total vitamin C Green-fleshed: Mean: 76.0 Range: 25.5-184.6 Yellow-fleshed: Mean: 125.4 Range: 64.4-205.8	Not determined	Not determined
Kiwifruit stored for 1-5 months at 0.5°C ± pre-treatment with methyl salicylate (MeSA) vapour. AA by titration. Aghdam, 2011	Not determined	Not determined	AA (% of 1 m control) Control: 1 m: 60 5 m: 41 (-32%) 8-32μL/L MeSA: 1m: 63-75 (+5 to +25%) 5m: 46-58 (-3 to -23%)
3 commercial **melon** cultivars (and other inbred lines), 2 growing locations and 2 consecutive years. β-carotene by HPLC. Cuevas, 2008	β-carotene Mean: 1310 Range: 880-1960	β-carotene Mean (range) of 2 years and 2 locations for each cultivar: Sol Dorado: 1520 (1070-1960) Esteem: 1080 (880-1240) Top-Mark: 1330 (1050-1790)	Not determined
3 **melon** types. AA measured spectrophotometrically Kolayli, 2010	AA Mean: 15.4 Range: 5.4-22.5	Not determined	Not determined
46 **persimmon** cultivars; 42 astringent and 14 non-astringent. Carotenoids by HPLC Zhou, 2011	Retinol equivalents Astringent: Mean: 39.9 Range: 11.8-90.6 Non-astringent: Mean: 19.6 Range: 8.6-35.4	Not determined	Not determined
5 **watermelon** cultivars. Total vitamin C measured	Total vitamin C Mean: 14.9	Not determined	Not determined

Study	Variety	Season / Growing conditions	Storage
spectrophotometrically, carotenoids by HPLC Tlili, 2011a	Range: 12.0-20.4 β-carotene Mean: 150 Range: 100-210 Lycopene Mean: 5270 Range: 4450-6450		
6 **watermelon** cultivars. Total vitamin C measured spectrophotometrically Tlili, 2011b	Total vitamin C Mean: 17.7 Range: 10.5-24.0	Not determined	Not determined
Total carotenoids measured in 26 **watermelon** cultivars by HPLC. Perkins-Veazie, 2006	Total carotenoids Mean: 7780 Range: 3710-12190	Not determined	Not determined

In summary, as with other fruit classes, vitamin C and carotene contents varied greatly between cultivars of the same fruit, with up to 8 to 10-fold variations in AA content of kiwifruit and carotene content of persimmon cultivars, respectively. AA content also decreased by up to 32% with storage of kiwifruit.

1.7. Cucurbit vegetables

In the national nutrition surveys, cucurbit vegetables were grouped under the “other fruiting vegetables” category in Australia, and as “other vegetables” and “orange vegetables” in New Zealand. In Australian children aged 2-16 years, “other fruiting vegetables” were not a major contributor to carotene or vitamin C intake. In Australians aged 17 years or over, 9-18% of dietary carotene was derived from other fruiting vegetables. In Australian females aged 19-29 years, and both male and female Australians aged 30 years or over, 5-6% of dietary vitamin C intake was derived from “other fruiting vegetables”, with vitamin C from capsicum likely being a major contributor to this intake. “Other vegetables” did not make a major contribution to carotene or vitamin C intakes in any of the New Zealand population groups studied. However, “orange vegetables” contributed to 35-61% of dietary carotene intakes in all New Zealand populations. These vegetable categories were not major contributors to vitamin E, B6, thiamin, riboflavin, niacin or folate intakes.

The cucurbits include various types of pumpkin, also known as winter squash, as well as zucchini and cucumber. As shown in Table 1.7.1, the carotene levels vary >100-fold between different cucurbits. Vitamin C levels also range up to 10-fold, with similar values reported in published literature (Mawamba et al. 2009). The effects of cooking are more varied, with good preservation of carotene in boiled and baked pumpkin (see Table 1.7.1). In contrast, boiling is associated with 13-27% loss of vitamin C, and steaming led to 44-66% vitamin C losses, depending on the type of pumpkin or squash (Table 1.7.1 (Mawamba et al. 2009)). In this study, steaming also led to 74-91% loss of β-carotene, which is in contrast to the effects of boiling or baking as detailed in Table 1.7.1. β-carotene levels in different cucurbits varied from 5-67 μg/g, with lower levels in zucchini, and higher levels in pumpkins (Azevedo-Meleiro and Rodriguez-Amaya 2007). Intra-variety differences in this study ranged from 13-29%.

Table 1.7.1 β-carotene (μg/100 g) and C (mg/100g) content of cucurbit vegetables.

Fruit	β-carotene		Vitamin C		
	NUTTAB[a]	NZ	NUTTAB[a]	NZ	USDA[a]
Cucumber	**78-250**	**59-83**	**7-13**	**1-13**	**3**
Pumpkin (winter squash)	**433-2710**	**n.a.**	**8-24**	**n.a.**	**2-21**
Pumpkin (baked)	*484-3029*	*3170*	*8-24*	*10*	*10-15*
Pumpkin (boiled)	*406-1575*	*3530*	*7-19*	*19*	*4-7*
Zucchini	**80-243**	**610**	**22-30**	**0**	**18**
Zucchini (boiled)	*86-275*	*n.a.*	*22-29*	*n.a.*	*13*

[a]Where values are provided for different varieties a range is given.

In summary, little published data were available on the effects of cultivar, growing condition and storage on nutrient composition of cucurbit vegetables. From nutrient composition tables, the vitamin C and carotene content varied between cultivars of cucumber, pumpkin and zucchini. In contrast to fruits, these nutrients were relatively stable during cooking.

1.8. Fruiting vegetables

In the nutrition surveys, fruiting vegetables are included in the minor food groups “tomato and tomato products”, “other fruiting vegetables” and “other vegetables”, with sweet corn in the “beans/peas/corn” group for the New Zealand surveys.

Tomato and tomato products contributed to 5% of carotene intake in Australian boys aged 14-16 years, but were not major contributors to carotene intake in other population groups. Tomato and tomato products contributed to 5-8% of vitamin C intake in Australian and New Zealand adults aged 30 years and above, but not in younger age groups. As indicated in the previous section, “other fruiting vegetables” contributed 9-18% of carotene intakes in

Australian adults, but this was due to the inclusion of pumpkins in this food group. “Other fruiting vegetables” contributed to 5-6% of dietary vitamin C intake in Australian adults aged over 30, and Australian females aged 19-30 years. None of the minor food groups “tomato and tomato products”, “other fruiting vegetables”, or “other vegetables” made a major contribution to vitamin E, B6, thiamin, riboflavin, niacin or folate intakes. In New Zealand, beans/peas/corn were not major contributors to vitamin A, C, E, B6, thiamin, riboflavin, niacin or folate intakes.

Table 1.8.1 β-carotene (µg/100 g) and vitamin C (mg/100 g) content of fruiting vegetables

Fruit	β-carotene		Vitamin C		
	NUTTAB[a]	NZ	NUTTAB[a]	NZ	USDA[a]
Capsicum (green)	**161**	**117**	**98**	**24**	**80**
Capsicum (red/yellow)	**282**	**930**	**152**	**144**	**184 (yellow)**
Chilli	**140-1370**	**n.a.**	**128-201**	**n.a.**	**45-243**
Eggplant	**39**	**n.a.**	**3**	**n.a.**	**2**
Eggplant (cooked)	*38-62*	n.a.	*2-4*	n.a.	*2*
Sweet corn	**60**	**n.a.**	**5**	**n.a.**	**7**
Sweet corn (boiled)	*6*	*120*	*4*	*3*	*6*
Sweet corn (canned)	*23*	*158*	*3*	*5*	*2*
Sweet corn (frozen)	*6*	*n.a.*	*4*	*n.a.*	*6*
Tomato	**60-460**	**549**	**16-28**	**24**	**9-16**
Tomato (canned)	*393-420*	*209*	*10*	*8*	*8-9*

Large variations in AA were observed in a study of fourteen tomato genotypes, with levels ranging from 1-35 mg/100 g (Roselló et al. 2011). In this study, tomatoes were grown in Spain in either a glasshouse during spring/summer and autumn/winter, or in an open-field during spring/summer. Genotype was the main source of variation, but environment also affected AA levels, with lowest levels in tomatoes grown during autumn/winter. β-carotene content was less dependent on environment, but showed similar variation between genotype, with levels ranging from 400-3500 µg/100 g (Roselló et al. 2011). In twelve salad tomato varieties, AA ranged from 15-21 mg/100 g and total carotenoids ranged from 6.3-9.9 mg/100 g (Abushita et al. 2000).

In a study of three tomato cultivars, AA levels increased 1.3- to 2-fold with ripening, and Total vitamin C content ranged from 8-15 mg/100 g between ripe fruit (Periago et al. 2009). A study of cherry tomatoes found no significant change in AA content with ripening, but total carotenoid levels increased >10-fold (Raffo et al. 2002). However, in cherry tomatoes harvest time had a significant effect on AA, total vitamin C and carotenoid levels (Raffo et al. 2012). In this study total vitamin C levels ranged 2.3-fold and AA levels 2.8-fold, with AA representing 38-61% of total vitamin C in tomatoes harvested at 6 times within a 12 month period (see Table 1.8.2 for details). Carotenoid levels also varied by 1.8-fold, but neither vitamin C nor carotenoid levels showed a clear correlation with harvest time, solar radiation or temperature. Year-to-year variation is also evident in tomatoes, with mean AA levels varying 1.9-fold between consecutive years in a study of 16 cultivars (Erge and Karadeniz 2011). Total carotenoids were less effected by year, but varied by up to 3.9-fold between cultivars.

The effect of storage in tomatoes is dependent on cultivar, time and temperature. In a study of five cultivars stored for 5 days at 15°C, AA levels decreased 12-34% in four strains, but increased 16% in another cultivar (Molyneux et al. 2004). In another study of 4 tomato cultivars, AA levels increased in tomatoes stored for 15 days and 6°C and 12°C, but decreased by 15% in tomatoes stored at 25°C (Vinha et al. 2013). In industrial tomatoes, AA levels were similar between cultivars, but decreased 55% with processing to tomato paste, while total carotenoids ranged from 6.8-13.2 mg/100 g, and were increased in tomato paste in association with higher lycopene levels (Abushita et al. 2000). Processing of tomatoes to sauce or soup did not significantly change AA levels, whereas baking (at 180-220°C for 45 minutes) and juicing with sterilization decreased AA content by 42-66% (Gahler et al. 2003). Similarly, thermal processing of tomatoes at 88°C for 2-30 minutes decreased vitamin C content by 10-29% (Dewanto et al. 2002). The nutrient compositions of canned tomatoes also demonstrate large losses of carotene and vitamin C (Table 1.8.1).

Table 1.8.2 Natural variation and effects of season, storage and processing on carotene (μg/100 g) and vitamin C (mg/100 g) levels in tomato

Study	**Variety**	**Season / Growing conditions**	**Storage or processing**
3 tomato cultivars. AA and lycopene by HPLC. Periago, 2009	AA Mean: 10.4 Range: 7.9-15.4 Lycopene[1] Mean: 5.0 Range: 3.0-6.8	Not determined	Not determined
5 tomato cultivars, stored for 2 or 5 days at 15°C in the dark. AA by titration and lycopene by spectrophotometry. *NOTE: data in mg/100 g* ***dry*** *weight* Molyneux, 2004	AA Mean: 212 Range: 192-237 Lycopene[1] Mean: 35.0 Range: 27.5-46.1	Not determined	AA Mean (range) 2d: 205 (173-247) -3% 5d: 185 (133-224) -12% Lycopene[1] 2d: 38.9 (28.5-55.1) +11% 5d: 47.1 (32.2-62.4) +35%
2 cherry tomato cultivars (pooled for analysis), harvested at ripe stage in April, June, July, December, January and March. AA, total vitamin C, and carotenoids by HPLC. Raffo, 2012	Not determined	AA Mean: 28 Range: 16-44 Total vitamin C Mean: 56 Range: 31-71 Total carotenoids Mean: 11779 Range: 8353-15119	Not determined
3 tomato cultivars and 11 experimental genotypes grown in 2 locations and 2 seasons as indicated. AA by capillary zone electrophoresis and carotenoids by spectrophotometry. Rosello, 2011	Overall mean and range (all seasons and locations) AA Mean: 14.5 Range: 0.6-34.6 β-carotene Mean: 1560 Range: 400-3500	AA Turis Spring/Summer: 18.5 (11.3-34.6) Valencia Spring/Summer: 15.2 (10.9-25.0) Valencia Autumn/Winter: 9.9 (0.6-33.1)	Not determined
27 tomato cultivars; 12 for fresh-eating, 15 for processing. Processing of one cultivar to tomato paste. AA and carotenoids by HPLC Abushita, 2000	AA Fresh-eating: Mean: 17 Range: 15-21 Processing: Mean: 19 Range: 17-21 β-carotene Fresh-eating: Mean: 424 Range: 285-617 Processing:	Not determined	AA mg/g dry matter Raw: 3.2 Hot-break extract: 2.0 (-38%) Paste: 1.5 (-53%)

Study	Variety	Season / Growing conditions	Storage or processing
	Mean: 310 Range: 210-447		
16 tomato cultivars harvested in 2 consecutive years. AA and carotenoids by HPLC. Erge, 2011	Not determined	AA Mean (range) 2003: 4.0 (2.2-7.4) 2004: 7.5 (2.7-13.8) Total carotenoids 2003: 19.4 (8.1-31.6) 2004: 23.2 (13.1-34.1)	Not determined
4 tomato cultivars stored at 6°C, 12°C and 25°C for 15 days. AA by titration and lycopene by spectrophotometry. Vinha, 2013	Day 1: AA Mean: 50.8 Range: 39.8-72.1 Lycopene Mean: 50.4 Range: 40.5-60.1	Not determined	Day 15: AA 6°C: 60.2 (+18%) 12°C: 56.6 (+11%) 25°C: 43.4 (-15%) Lycopene 6°C: 44.6 (-12%) 12°C: 41.5 (-18%) 25°C: 39.8 (-21%)
Cooking of tomatoes by baking for 15-45 min at 180-220°C, or boiling peeled tomatoes with cream to process to soup. AA by HPLC Gahler, 2003	Not determined	Not determined	AA Baking: 0 min: 12.8 15 min: 12.9 30 min: 10.1 (-21%) 45 min: 6.4 (-50%) Soup: 0 min: 12.4 50 min: 11.5

[1]Lycopene data presented for tomatoes when total carotenoid data not available

Carotenoid content in capsicum increases with maturity in all species, with large differences between species and cultivars (Table 1.8.3, Howard, 2000). For example, β-carotene levels ranged from 18-247 µg/100 g in immature *C. annuum* cultivars, and increased to 337-800 µg/100 g in mature fruit. AA also increased with maturity with levels ranging from 102-202 mg/100 g in mature capsicums (Howard et al. 2000). Similar patterns in carotenoid and AA levels were observed with other capsicum species, including chilli (Howard et al. 2000; Marín et al. 2004). In ripe red capsicum, AA levels decreased by 24-26% with 10 to 20 days storage at room temperature, and by 16% after 20 days at 4°C (Martínez et al. 2005). In the same study, AA losses of 20-25% were reported after canning, 12% after blanching, and 13-40% after freezing.

Table 1.8.3 Natural variation and effects of season and storage on carotene (µg/100 g) and vitamin C (mg/100 g) levels in fruiting vegetables other than tomato.

Study	**Variety**	**Season / Growing conditions**	**Storage or processing**
7 **capsicum** cultivars (including sweet and tabasco and habanero chillis). AA and carotenoids (µg RE/100 g) by HPLC Howard, 2000	AA Mean: 127.0 Range: 74.6-202.4 RE Mean: 177 Range: 0.3-336	Not determined	Not determined
Fresno de la Vega **capsicum** harvested in 2 consecutive years and stored for 10 or 20 days at 4°C and 20°C. Effect of blanching, freezing (with 30 d storage), drying and canning on AA also measured. Enzymatic analysis of AA. Martinez, 2005	Not determined	AA 1997: 148.9 1998: 159.6 Not significant	AA 10 days: 4°C: 153.8 (-4%) 20°C: 121.8 (-24%) 20 days: 4°C: 134.1 (-16%) 20°C: 118.8 (-26%) Processing: Blanch: 140.7 (-12%) Freeze: 95.5 (-40%) Blanch + Freeze: 138.4 (-13%) Freeze dry: 19.2 (-88%) Fry / roast then can: 119.7 / 127.7 (-25% / -20%)
87 inbred **corn** lines grown in 2 consecutive years. Carotenoids measured by HPLC. Chander 2008	Pool of 2 years β-carotene Mean: 44.9 Range: 1.6-172.6 Total carotenoids Mean: 1030 Range: 10-2250	Year: β-carotene 2004: 37.1 2005: 52.8 Total carotenoids 2004: 872 2005: 1188	Not determined
44 **corn** genotypes including sweet and dent corn. Carotenoids measured by HPLC as µg/100g dry weight. Kurilich, 1999	β-carotene Mean: 68 Range: 7-764 Total carotenoids Mean: 1041 Range: 15-3311	Not determined	Not determined
35 **eggplant** genotypes grown in 2 consecutive years. Total vitamin C by titration and presented mg/100g dry weight. Hanson, 2006	AA Mean: 86 Range: 56-129	Significant effect of year, but details of individual years not presented	Not determined
69 **eggplant** genotypes, including varieties of *S. melongena* Spanish, African and Caribbean landraces, commercial	AA *S. melongena*: Spanish: 1.8 (1.5-2.2) African: 1.3 (1.0-1.8) Caribbean: 2.0	Not determined	Not determined

Study	Variety	Season / Growing conditions	Storage or processing
hybrids and non-hybrids, experimental hybrids as well as 2 varieties of *S. aethiopicum* and *S. macrocarpon*. AA by titration. Prohens, 2007	Hybrid: 1.7 (1.6-1.9) Non-hybrid: 1.5 (1.0-2.1) Asian: 1.7 (1.3-2.2) Experimental: 1.8 (1.3-2.1) *S. aethiopicum*: 1.7-2.3 *S. macrocarpon*: 1.8-2.0		

The major carotenoids in corn are lutein and zeaxanthin, which are not vitamin A precursors. β-carotene is also found in corn, with levels ranging from 2-173 μg/100 g in a study of inbred lines, and 7-764 μg/100 g dry weight in a study of 44 corn types selected for variation in kernel colour, lipid and protein contents (Kurilich and Juvik 1999; Chander et al. 2008). As detailed in Table 1.8.1, boiled, frozen and canned corn has lower levels of carotene and vitamin C.

AA levels ranged from 56-129 mg/100 g in a study of 35 different eggplants (Hanson et al. 2006); these values are for dry mass and are therefore higher than those reported in food composition tables (see Table 1.8.1). In another study of 69 different eggplant varieties and hybrids the AA content ranged from 1-2 mg/100 g (Prohens et al. 2007). Carotene and vitamin C levels were minimally affected by cooking (Table 1.8.1).

In summary, there is a wide range in carotene and vitamin C levels in tomatoes, and this variability is further exaggerated by the influence of growing season, location and year. The effects of storage are variable, with some studies indicating reduced carotene and increased AA, and others showing the opposite. Other fruiting vegetables also show a large variation in nutrient composition between cultivars. Processing was associated with large reductions in vitamin C levels in both tomatoes and capsicums.

1.9. Summary of variation in nutrient composition in fruits and vegetables

From the above data, it is evident that the numerical values provided in nutrient composition tables provide only a general indication of carotene and vitamin C content in fruits and vegetables. For the majority of fruits and vegetables in this review, the vitamin C values in food composition tables were within the range reported in published literature. However, both apple and watermelon had higher vitamin C levels reported in the literature compared to that in nutrient composition tables. A likely source of this difference may be storage-associated diminution of vitamin C; in apples as much as 90% of vitamin C may be lost during storage.

Overall, these data emphasise the extensive variation in carotene and vitamin C levels that occurs between cultivars, and the additional influence of growing conditions, location and season, as well as postharvest handling and storage on nutrient composition of fruits and vegetables. These factors have a significant impact on the vitamin content of fruits and vegetables that are ultimately consumed by the Australian and New Zealand populations.

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