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Carotenoid and folate content of heirloom tomatoes: 2024

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Executive summary

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The Heritage Food Crops Research Trust (HFCRT) provided 28 heirloom tomato (*Solanum lycopersicum*) samples for measurement of carotenoids and folate. The heirloom varieties are known to contain the carotenoid tetra-*cis*-lycopene, which is easily absorbed when eaten raw, and this is of particular interest to HFCRT.

Carotenoids measured were lutein, all-*trans*-lycopene, tetra-*cis*-lycopene, phytoene, phytofluene, *zeta*-carotene, *beta*-carotene, and additionally two unidentified compounds, from a previous study, which are thought to be carotenoids. Carotenoids concentrations were in alignment with those reported in tomatoes in previous years and varied between cultivars. Twenty-six of the provided tomato cultivars contained tetra-*cis*-lycopene and higher concentrations of the carotenoids phytoene, phytofluene and *zeta*-carotene, which are biosynthetic precursors to tetra-*cis*-lycopene. Two tomato samples did not contain tetra-*cis*-lycopene and the intermediates phytoene, phytofluene, and *zeta*-carotene were lowered or not detected, but did contain *beta*-carotene.

Folate (vitamin B9) was observed in all tomato samples at varying concentrations, and ranged from 12.8 to 37.7 µg/100 g.

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1 Introduction

The Heritage Food Crops Research Trust (HFCRT) is interested in the health benefits of plant-based food to improve human health. The heirloom tomatoes (*Solanum lycopersicum*) available for consumers by HFCRT are of the golden/orange varieties. Identifying tomato cultivars and selections that have greater concentrations of nutritional and bio-active compounds such as carotenoids, polyphenols, and folate (vitamin B9) than conventionally grown commercial tomatoes (red tomatoes) is of interest to HFCRT. The heirloom varieties are known to contain the lycopene form (tetra-*cis*- lycopene) which is easily absorbed when eaten raw, unlike all-*trans*-lycopene. HFCRT researchers have found that tomatoes containing tetra-*cis*-lycopene are likely to be more orange (but can still fall within the golden to orange colour spectrum), whereas tomatoes with *beta*-carotene tend to be more consistently golden (rather than orange) (Mark Christensen, personal communication 2024).

The New Zealand Institute for Plant and Food Research Limited (PFR) has measured carotenoids and polyphenols for many years (McGhie et al. 2022; McGhie & Cordiner 2021, Cordiner 2020) and in 2023 folate was measured (Stoklosinski & Martin 2023). This year the tomatoes were analysed to determine the concentrations of carotenoids and folate, and the methods employed were the same as 2023. The following reports the results for tomato samples provided during the 2024 summer by HFCRT.

2 Materials and methods

Twenty-eight samples of tomato, along with their descriptions, were provided by Mark Christensen, HFCRT, Wanganui, and details are provided in Table 1. Tomato samples were couriered fresh, and once received at PFR, Palmerston North, were immediately stored at −20°C until analysis. Photos of the 28 frozen tomato samples are shown in the Appendix, Figure A1.

Lab reference: HX22

Table 1. Details of the tomato samples provided for analysis by Heritage Food Crops in 2024.

Sample name	Colour code	Description
Amish Orange Oxheart 2	blue	A 2024 selection from an 'Amish Orange Oxheart 2' plant
Amish Orange Oxheart 2 – renamed 'Amish Star'	green	A 2024 selection from an 'Amish Orange Oxheart 2' plant
Carol	pink	A 2024 selection from an 'Oracle 2 SBO V.2' plant
Carol	yellow	A 2024 selection from an 'Oracle 2 SBO V.2' plant
Eye Drop V2	red	A 2024 selection from an 'Eye Drop V.2' plant
Gleam	green	A 2024 selection from an 'Optical S1' plant
Glimpse	green	A 2024 selection from a 'Best Optical M V.2' plant
Golden Bell V2	pink	A 2024 selection from a 'Golden Bell V.2' plant
Golden Grape	red	A 2024 selection from a 'Golden Grape' plant
Golden Light V3	green	A 2024 selection from a 'Golden Light V.3' plant
Golden Light V3	blue	A 2024 selection from a 'Golden Light V.3' plant
Golden Light V3	pink	A 2024 selection from a 'Golden Light V.3' plant
Mango Tomato	yellow	Golden medium-sized tomato
Mini Orange V2	pink	A 2024 selection from a 'Mini Orange V.2' plant
Moonbeam V2	pink	A 2024 selection from a 'Moonbeam V.2' plant
Moonglow V3	blue	A 2024 selection from a 'Moonglow V.3' plant
Moonglow V3	red	A 2024 selection from a 'Moonglow V.3' plant
Moonglow V3	indigo	A 2024 selection from a 'Moonglow V.3' plant
Oley V2	pink	A 2024 selection from an 'Oley V.2' plant
Oley V2	yellow	A 2024 selection from an 'Oley V.2' plant
Olga's Round Golden Chicken Egg V2	yellow	A 2024 selection from an 'Olga's Round Golden Chicken Egg V.2' plant
Optical (end of row V4)	pink	A 2024 selection from an 'Optical (end of row V.4)' plant
Spirited	yellow	A 2024 selection from a 'Spirited' plant
Spirited	blue	A 2024 selection from a 'Spirited' plant
Spirited	pink	A 2024 selection from a 'Spirited' plant
Tangella	pink	A 2024 selection from a 'Tangella' plant
Tangella	orange	A 2024 selection from a 'Tangella' plant
Wally's Spanish	with potato leaf	A 2024 selection from a 'Wally's Spanish' plant

2.1 Carotenoid analysis

The analytical method used for the measurement of carotenoids in this study was similar to the 2020 tomato study (McGhie & Cordiner 2020). In brief, after carotenoid extraction, analysis was performed using a Thermo Vanquish Horizon ultra high-pressure liquid chromatograph (UHPLC) (with a photo diode array detector (PDA)), providing retention time and unique UV/Vis absorption profile for each carotenoid. Details of the carotenoids measured are shown in Table 2.

Where authentic standards were not available, the concentrations for these carotenoids were calculated using surrogate (equivalence) standards as shown in Table 2. Corrections were based on relative extinction coefficients at the detection wavelength (nm) used for each carotenoid. Tetra-*cis*-lycopene concentrations were calculated using an all-*trans*-lycopene standard, whereas phytoene, phytofluene and *zeta*-carotene concentrations were calculated using a *beta*-carotene standard. The accuracy of the absolute concentration values should be treated with caution and comparison with quantitative data from other studies should be made with care.

This analysis includes two unknown compounds which were reported in 2021 but not chemically identified (McGhie & Cordiner 2021). However, the compounds have unique UV/Vis absorption profiles, and these were utilised to measure unknown A and unknown B.

Unknown A describes a previous discussed unidentified carotenoid (U2). Its absorption is maximum at 432 nm (also known as its lambda max). Due to a lack of identification a relative extinction coefficients and therefore an appropriate response factor was not available, therefore unknown A was detected at 436 nm using the surrogate all-*trans*-lycopene.

Unknown B describes a carotenoid that had the same retention time as *beta*-carotene and a very similar UV/Vis absorption profile. However, this UV/Vis absorption profile was different and this knowledge has guided the correct reporting of *beta*-carotene in previous studies. Unknown B was detected at 450 nm using the surrogate *beta*-carotene.

Table 2. Details of carotenoid and unknown compounds analysed in tomatoes provided by Heritage Food Crops (2024).

Compound	CAS#	Formula	Exact mass	Detection wavelength (nm)	Equivalence
lutein	127-40-2	C40H56O2	568.428	450	lutein
all-trans-lycopene	502-65-8	C40H56	536.4382	470	all-trans-lycopene
tetra-cis-lycopene	2361-24-2	C40H56	536.4382	436	all-trans-lycopene
phytoene	13920-14-4	C40H64	544.5008	286	beta-carotene
phytofluene	540-15-6	C40H62	542.4852	348	beta-carotene
zeta-carotene	13587-06-9	C40H60	540.4695	400	beta-carotene
beta-carotene	7235-40-7	C40H56	536.4382	450	beta-carotene
unknown A	-	-	-	436	all-trans-lycopene
unknown B	-	-	-	450	beta-carotene

2.2 Folate analysis

Folate (vitamin B9) was measured in the tomato samples using a PFR in-house method developed by Martin et al. (2010). It is a high-throughput, homogeneous, fluorescence polarisation, and fluorescence intensity assay. Table 3 makes note of folate chemical detail.

Table 3. Details of folate analysed in tomatoes provided by Heritage Food Crops (2024).

Compound	CAS#	Formula	Exact mass
Folate	59-30-3	C19H19N7O6	441.1397

3 Results and discussion

It is prudent to note that factors such as maturity of fruit at harvest, postharvest storage conditions and environmental factors could have an affect on the concentrations of compounds and therefore have an impact on results; this should be taken into consideration.

3.1 Carotenoid concentrations

Carotenoid concentrations (measured as mg/100 g fresh weight) for the 28 tomato samples are shown in Table 4. Carotenoids measured were lutein, all-*trans*-lycopene, tetra-*cis*-lycopene, phytoene, phytofluene, *zeta*-carotene, *beta*-carotene, and the unknown carotenoids unknown A and unknown B. It is sometimes difficult to determine a chemical profile by the colour of the tomato alone. Chemical analysis, such as the carotenoid method performed here can provide these profiles.

As in previous years, three general profiles have emerged:

- When tetra-*cis*-lycopene is present, the intermediates phytoene, phytofluene and *zeta*-carotene are elevated, and *beta*-carotene and all-*trans*-lycopene are lowered or not detected.
- When all-*trans*-lycopene is present, tetra-*cis*-lycopene and the intermediates phytoene, phytofluene, and *zeta*-carotene are lowered or not detected.
- When *beta*-carotene is present, tetra-*cis*-lycopene and the intermediates phytoene, phytofluene, and *zeta*-carotene are lowered or not detected.

Twenty-six of the provided tomato cultivars contained tetra-*cis*-lycopene and higher concentrations of the carotenoids phytoene, phytofluene and *zeta* carotene, which are biosynthetic precursors to tetra-*cis*-lycopene.

Two tomato samples contained *beta*-carotene and tetra-*cis* lycopene not detected, and lower or not detected concentrations of the carotenoids phytoene, phytofluene and *zeta* carotene; these were Optical (red of row V4) and Eye Drop V2.

Two unknown compounds were also measured:

- Unknown A was detected at low levels in all 26 tomatoes that also contained tetra-*cis*-lycopene.
- Unknown B, which has a similar UV/Vis spectra and the same retention time as *beta*-carotene, was identified by utilising the UV/Vis absorption profile described in a previous report (McGhie & Cordiner 2021). Two tomato samples were identified as containing unknown B – these were Amish Orange Oxheart (2) and Mango Tomato. Unless identified as *beta*-carotene, other tomato samples did not have spectral properties identifying them as unknown B. On close investigation, their UV/Vis spectra were similar to unknown B and *beta*-carotene – but not close enough to be identified.

Table 4. Carotenoid concentrations (mg/100 g fresh weight) for tomatoes provided by Heritage Food Crops (2024).

Sample name	Colour code	tetra-*cis*-lycopene	phytoene	phyto-fluene	*zeta*-carotene	*beta*-carotene	all-*trans*-lycopene	lutein	unknown A	unknown B
Amish Orange Oxheart 2	blue	2.23	10.86	4.74	6.86	n.d.	n.d.	n.d.	1.49	0.25
Amish Orange Oxheart 2 - renamed 'Amish Star'	green	2.08	4.78	2.89	5.77	n.d.	n.d.	0.05	1.36	n.d.
Carol	pink	2.56	5.54	3.15	5.28	n.d.	n.d.	n.d.	1.39	n.d.
Carol	yellow	2.74	5.56	3.22	5.31	n.d.	n.d.	n.d.	1.42	n.d.
Eye Drop V2	red	n.d.	0.35	0.09	n.d.	3.08	n.d.	0.08	n.d.	n.d.
Gleam	green	1.55	12.06	4.29	4.80	n.d.	n.d.	n.d.	1.24	n.d.
Glimpse	green	1.94	4.85	2.28	3.62	n.d.	n.d.	0.07	0.68	n.d.
Golden Bell V2	pink	2.56	7.36	4.45	8.69	n.d.	0.06	0.13	1.88	n.d.
Golden Grape	red	2.34	4.55	2.92	2.52	n.d.	n.d.	0.05	0.72	n.d.
Golden Light V3	green	1.64	5.44	2.96	6.03	n.d.	0.07	0.07	1.24	n.d.
Golden Light V3	blue	1.10	5.83	3.29	7.37	n.d.	n.d.	0.07	1.42	n.d.
Golden Light V3	pink	1.18	5.73	2.56	6.03	n.d.	0.08	0.08	0.91	n.d.
Mango Tomato	yellow	1.82	11.69	5.53	11.19	n.d.	n.d.	n.d.	1.95	0.39
Mini Orange V2	pink	1.47	5.82	3.46	7.19	n.d.	n.d.	0.06	1.46	n.d.
Moonbeam V2	pink	2.80	5.44	3.36	7.21	n.d.	n.d.	0.06	1.84	n.d.
Moonglow V3	blue	1.85	6.60	3.83	6.41	n.d.	n.d.	0.05	1.51	n.d.
Moonglow V3	red	1.52	5.90	3.41	6.66	n.d.	n.d.	0.06	1.48	n.d.
Moonglow V3	indigo	2.33	4.91	2.95	4.30	n.d.	n.d.	0.05	0.99	n.d.
Oley V2	pink	2.77	7.99	4.91	9.66	n.d.	n.d.	0.05	2.23	n.d.
Oley V2	yellow	3.08	6.23	3.71	5.88	n.d.	n.d.	0.05	1.46	n.d.
Olga's Round Golden Chicken Egg V2	yellow	2.99	7.39	4.45	6.11	n.d.	n.d.	0.04	1.73	n.d.
Optical (end of row V4)	pink	n.d.	0.48	0.18	n.d.	4.06	n.d.	n.d.	n.d.	n.d.
Spirited	yellow	3.60	4.99	2.87	3.35	n.d.	n.d.	0.04	0.90	n.d.
Spirited	blue	3.38	9.53	5.50	10.31	n.d.	n.d.	0.05	2.67	n.d.
Spirited	pink	2.45	7.52	3.54	8.16	n.d.	n.d.	0.08	1.48	n.d.
Tangella	pink	2.80	4.97	2.93	5.51	n.d.	0.06	0.07	1.31	n.d.
Tangella	orange	1.77	4.28	2.65	6.13	n.d.	n.d.	0.07	1.30	n.d.
Wally's Spanish	with potato leaf	2.37	5.51	2.91	3.95	n.d.	n.d.	n.d.	1.04	n.d.

n.d. = not detected

3.2 Folate concentrations

Unlike plants, humans are not able to synthesise folate so require a plant source, such as tomato, to acquire it.

Folate concentrations (measured as µg/100 g fresh weight), for the 28 tomato samples are shown in Table 5. Folate concentrations ranged from 12.8 to 37.7 µg/100 g.

Table 5. Folate concentrations (µg/100 g fresh weight) for tomatoes provided by Heritage Food Crops (2024).

Sample name	Colour code	folate (ug/100g)
Amish Orange Oxheart 2	blue	32.8
Amish Orange Oxheart 2 - renamed ‘Amish Star’	green	24.9
Carol	pink	35.3
Carol	yellow	33.7
Eye Drop V2	red	37.7
Gleam	green	22.9
Glimpse	green	29.8
Golden Bell V2	pink	22.2
Golden Grape	red	36.5
Golden Light V3	green	22.4
Golden Light V3	blue	21.6
Golden Light V3	pink	25.1
Mango Tomato	yellow	12.8
Mini Orange V2	pink	23.1
Moonbeam V2	pink	29.3
Moonglow V3	blue	18.8
Moonglow V3	red	21.2
Moonglow V3	indigo	19.5
Oley V2	pink	23.2
Oley V2	yellow	30.5
Olga's Round Golden Chicken Egg V2	yellow	22.1
Optical (end of row V4)	pink	30.1
Spirited	yellow	31.6
Spirited	blue	24.8
Spirited	pink	37.5
Tangella	pink	23.7
Tangella	orange	26.1
Wally's Spanish	with potato leaf	20.4

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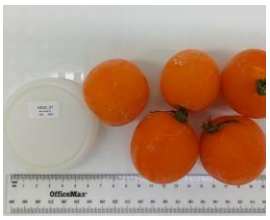
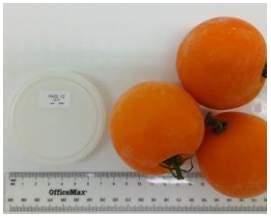
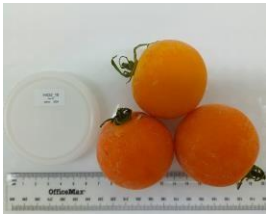
Appendix

			
Amish Orange Oxheart (2) - blue	Amish Orange Oxheart 2 - green	Carol - pink	Carol - yellow
			
Eye Drop V2 - red	Gleam - green	Glimpse - green	Golden Bell V2 - pink
			
Golden Grape - red	Golden Light V3 - green	Golden Light V3 - blue	Golden Light V3 - pink
			
Mango Tomato - yellow	Mini Orange V2 - pink	Moonbeam V2 - pink	Moonglow V3 - blue
			
Moonglow V3 - red	Moonglow V3 - indigo	Oley V2 - pink	Oley V2 - yellow

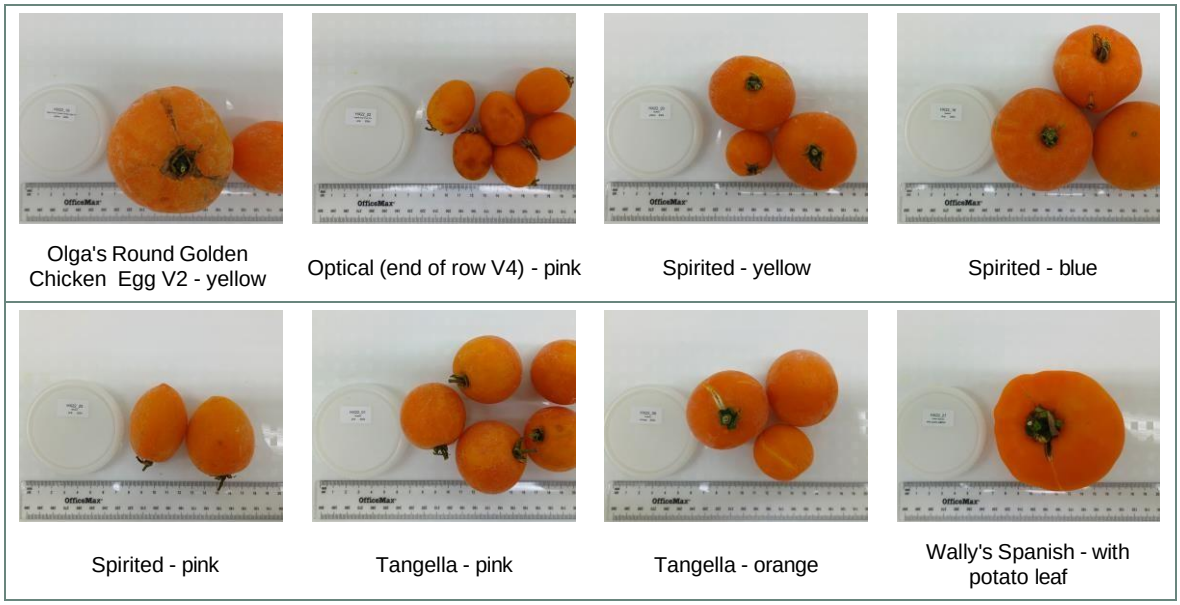


Figure A1. Photos of the 28 frozen tomato samples provided by Heritage Food Crops (2024).

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