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Te Kukunetanga: Vegetable and fruit intake during pregnancy

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ABSTRACT

Background: Carotenoids, found in vegetables and fruits, act as antioxidants and are a source of vitamin A. Carotenoids may play an important role in maternal and fetal health (e.g., eye health and brain development) and the prevention of pre-eclampsia, preterm birth, small for gestational age babies and/or intrauterine growth restriction. No studies have examined relationships among carotenoid concentrations, intake of vegetables and fruit, and weeks of gestation. Understanding of the stability of carotenoid concentrations across gestation, despite increasing demands placed on the body (e.g., increase in metabolic demands, body mass and volume), may help inform specific guidelines for vegetable and fruit intake during pregnancy.

Aim: This study aimed to investigate the relationships of vegetable and fruit intake, body mass, volume, density and gestation with the carotenoid reflection score.

Method: Carotenoid concentration in the fat of women throughout their pregnancy was assessed using a non-invasive Veggie Meter™ device which measures carotenoid reflection spectroscopy from the fingertip. Gestation and vegetable and fruit intake were self-reported. Body mass and body volume were measured via a 3D body scanner and force plate. Correlations between baseline visit measures, differences between visit I and II and repeated measures correlations (up to four visits) were analysed for all measures.

Findings: Only nine of the 35 women (25.7%) in this study met the guideline of 7+ a day for vegetable and fruit intake. Carotenoid reflective scores tended to be lower for those with greater body mass ($r = -0.48$, 95% CI = -0.70, -0.18; $p < 0.001$) and volume ($r = -0.50$, 95% CI = -0.71, -0.20; $p < 0.001$). Although women increased their vegetable and fruit intake with increased gestation ($rrm = 0.60$, 95% CI = 0.2, 0.83; $p = 0.01$), their carotenoid reflective score did not increase ($rrm = -0.29$, 95% CI = -0.66, 0.19; $p = 0.22$).

Conclusion: Supporting previous recommendations for the general population that vegetable and fruit intake should increase relative to body size, the current study findings suggest it may be advisable for women to progressively consume more vegetables and fruit to align with increases in body mass throughout pregnancy.

Keywords: carotenoid, pregnant, gestation, biomarker, Veggie Meter™

INTRODUCTION

During pregnancy the consumption of nutrient-dense foods is necessary to support the rapid growth and development of the fetus and maintain optimal maternal health. Evidence-based dietary guidelines (Ministry of Health, 2022a) for women (see language statement, p. 5) during pregnancy advocate for the consumption of at least five servings of vegetables and two servings of fruit every day; quantities which in 2021 were reported as being consumed by only 10% of the New Zealand population (Ministry of Health, 2022b). Diverse micronutrients of vitamins, minerals and phytochemicals are consumed when vegetables and fruit of a variety of colours are consumed, ideally making up half the volume of food eaten.

Self-reports of vegetable and fruit intake may not be reliable or accurate; therefore, objective measures of biomarkers of vegetable and fruit intake are needed. A validated biomarker of total vegetable and fruit intake is the carotenoid concentration in plasma (Yuan et al., 2022). While carotenoids are found in most plants, good sources of fat-soluble β carotene and other carotenoids are particularly high in certain foods, including dark green leafy vegetables, carrots, pumpkins and tomatoes. Vegetables and fruits account for 80-90% of dietary carotenoid intake (Maiani et al., 2009). Recently it has been shown that carotenoid status can be determined by measuring the colour or carotenoid reflective score of the skin (fat-pad) at the fingertip, using reflective spectroscopy within a non-invasive

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instrument called the Veggie Meter™ (Longevity Link, Utah, United States). Carotenoid reflective scores are a strong predictor of plasma carotenoid status and dietary intake of carotenoids in children and adults (Jilcott Pitts et al., 2022; Nguyen et al., 2015) and have demonstrated validity and reliability in diverse settings (Hasnin et al., 2023), independent of skin melanin levels (Ermakov et al., 2018). No studies have investigated this relationship in pregnant women.

Carotenoids function as antioxidants, which support the immune system and are also precursors of vitamin A, which is essential for eye health and brain development (Prihastyanti et al., 2021). Developing fetuses and infants depend entirely on maternal intake of carotenoids for pro-vitamin A requirements (Alwakeel et al., 2021). As well as supporting the immune system, carotenoids can partially reduce damage from oxidative reactions and decrease inflammatory responses. Hence carotenoids may play an important role in prevention of pre-eclampsia, preterm birth, small for gestational age (SGA) babies and/or intrauterine growth restriction (Zielińska et al., 2017). The lower vitamin A and β-carotene status in women with pre-eclampsia, compared to women who are normotensive, may be a measure of oxidative stress associated with a reduced dietary intake of all exogenous antioxidants, including vitamins C and E, minerals zinc and selenium, and other phytochemicals (Chiarello et al., 2020). Diet is one of the best ways under our control to improve antioxidant status.

Throughout pregnancy, carotenoid concentrations will be influenced by vegetable and fruit intake, increased metabolic demands of cell division and growth of both the mother and the fetus. Increases in extracellular fluids and fat mass will increase the overall body mass and volume of the body and influence the concentration of carotenoids.

Changes in body composition across pregnancy can be represented by a measure of body density, which decreases as body fat increases. An increase in fat mass would be expected to have a dilution effect on carotenoid concentrations, therefore requiring increased carotenoid-rich food intake to achieve the equivalent carotenoid reflective scores to those of an individual with a lower mass of body fat. Research into the relationship between body mass, volume, density and carotenoid reflective scores is required to understand the effect of pregnancy on carotenoid concentrations. While the increased plasma volume of pregnancy has a dilution effect on several micronutrients, the bioavailability and absorption mechanisms also increase (King, 2001). This study has measured the effects of pregnancy on carotenoid concentration; however, further research is needed before clear guidance can be developed about recommended quantities of fruit and vegetables for pregnant women.

As a modifiable factor during pregnancy, maintenance or increase of vegetable and fruit intake is a cornerstone of advice to pregnant women. The research programme Te Kukunetanga: Developing Cycle of Life aims to improve the pregnancy journey and outcomes for wāhine and their whānau (family group/extended family). This paper reports on a sub-study of Te Kukunetanga.

AIM

This pilot/feasibility study aimed to investigate the relationships of vegetable and fruit intake, body mass, volume, density and gestation with the carotenoid reflection score as measured by the Veggie Meter™.

METHOD

Study design

This cross-sectional study represented a convenience sample that varied by age and pregnancy gestation.

Participants

Women involved in the longitudinal Te Kukunetanga research programme were invited to take part in a sub-study to look at the relationship between carotenoid status and vegetable and fruit intake during pregnancy. Inclusion criteria for Te Kukunetanga were being pregnant and aged 18 to 40 years old. Recruitment strategies included advertising via midwifery practices, social media, Ngāti Whātua Ōrākei Iwi Engagement and radio stations, with the aim to recruit a representative cohort for the population of Auckland. We did not ask about gender identity.

Data collection

Ethics approval was gained from Auckland University of Technology (approval #22/144). All women provided signed informed consent forms before taking part. Self-reported gestation week was recorded. Vegetable and fruit intake was measured using two questions adapted from the New Zealand Health Survey (Ministry of Health, 2022b). Specifically, participants were asked: 1) how many servings of fruit do you eat in one week? and 2) how many servings of vegetables do you eat in one week? Serving sizes were standardised (Ministry of Health, 2020) and answers were converted to serves per day for analysis. At the time of the measurement there was discussion about food variety and particularly the need for colourful vegetables in the diet. The revised guideline of 7+ a day, five vegetables and two pieces of fruit, was shared. Women were asked about specific carotenoid-rich foods (Ministry of Health, 2022b) consumed frequently in New Zealand via a previously validated questionnaire (Amoah et al., 2023). These foods included pumpkin, carrots, dark green leafy vegetables and tomatoes.

The Veggie Meter™ device was calibrated with white and black reference cards. Following cleaning of the fingertip of the woman's right hand index finger, the fingertip was pressed on the lens and the reflection score recorded. This was repeated three times and a fourth measurement made if the variation was more than 10%. A single researcher collected all data to minimise user error. Average carotenoid reflection score values were calculated for each visit.

Each woman wore a standardised sports bra, shorts and hair compression cap, and a 3D body surface image was captured of her while she was standing on a force plate. To reduce the influence of air in the lungs, participants were asked to fully exhale and hold their exhale for the duration of time it took to capture the image from neck to pelvis. Body mass and volume measures were exported from Anthroscan Basis software (v3.0.1, Human Solutions, Kaiserslautern, Germany). Estimated body density was calculated as mass/volume.

Statistical analyses

Descriptive data are reported as mean and standard deviation. Pearson's correlation analysis was used to explore the strength of the relationships between baseline (visit I) measurements (i.e., correlations) of carotenoid reflective score, gestation, fruit and vegetable intake, carotenoid food intake, body mass (measured in kilograms [kg]), body volume (measured in litres [l]) and body density (measured in kilograms per litre [$kg.l^{-1}$]). Associations between measures were determined by visual inspection of scatter plots and interpreted using Pearson correlation effect sizes (r) where 0.2 was a small correlation, 0.5 was moderate and 0.8 large (Sullivan & Feinn, 2012), 95% confidence intervals (CI) and p-values with alpha set at 0.05.

One-tailed paired t-tests to investigate differences in the listed measures between baseline and the second (repeated) visit were undertaken for women who had completed two visits. Using all data captured (up to four visits), repeated measures correlations

(r_{rm}) were calculated with 95% CI and p-values (shiny app: https://lmarusich.shinyapps.io/shiny_rmcorr/) to further investigate relationships between variable couplings. Effect sizes (r_{rm}) strength was interpreted as small (r_{rm} > 0.1), moderate (r_{rm} > 0.3) and large (r_{rm} > 0.5; Bakdash & Marusich, 2017; Marusich & Bakdash, 2021).

FINDINGS

Thirty-five women were recruited to this study. Each participant completed a baseline data collection session and repeated sessions were completed by 14 participants within the time of this study. Participants were aged 32 ± 4 years (range = 20-39 years); 54% (n = 19) were NZ European/Pākehā, 11% (n = 4) were NZ Māori, 20% (n = 7) were Other European, 11% (n = 4) were Asian and one participant was Latin American.

As shown in Table 1, at visit I the 35 women varied across trimester 1 (n = 1), trimester 2 (n = 15) and trimester 3 (n = 19) of pregnancy. The cohort exhibited a wide variation in body mass (2.5 times), carotenoid reflective scores (3.6 times) and vegetable and fruit intake (3.3 times). Body density for the cohort indicated a variation in body composition; the lower the density of the body, the higher the percentage of body fat (i.e., density of fat is ~0.9 $kg.l^{-1}$ and lean muscle mass is ~1.1 $kg.l^{-1}$). Only nine of the 35 women (25.7%) met the guideline of 7+ a day for vegetable and fruit intake. The carotenoid reflection score of five women (14%) was less than 250, which is considered the lower cut-point for health (Rush et al., 2020).

Table 1. Mean ± SD and range values for variables at baseline collection for 35 pregnant women

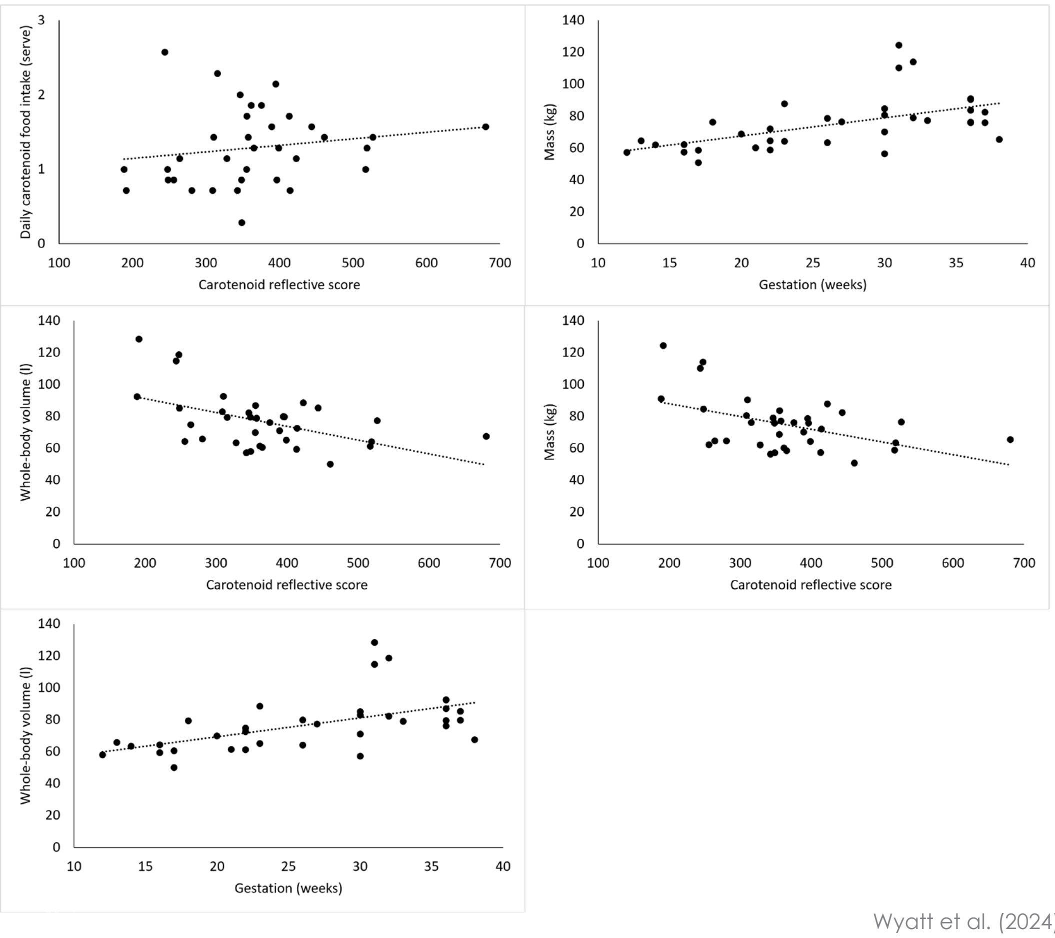
	Mean ± SD	Range
Gestation (weeks)	26 ± 8	12-38
Body mass (kg)	74.9 ± 16.6	50.8-124.4
Body volume (l)	77 ± 17	50-128
Body density ($kg.l^{-1}$)	0.98 ± 0.01	0.95-1.01
Carotenoid reflective score	363 ± 101	189-681
Vegetable and fruit intake (serve/day)	5 ± 2	3-10
Carotenoid food intake (serve/day)	1 ± 1	0-3

Table 2. Correlation matrix (r-values) for 35 pregnant women at baseline collection session

	Gestation	Body mass	Body volume	Body density	Carotenoid reflective score	Vegetable and fruit intake	Carotenoid food intake
Gestation	1						
Body mass	0.55+*	1					
Body volume	0.55+*	0.99++	1				
Body density	-0.23	-0.26	-0.34	1			
Carotenoid reflective score	0.04	-0.48*	-0.50+*	0.13	1		
Vegetable and fruit intake	0.21	-0.08	-0.08	-0.02	0.31*	1	
Carotenoid food intake	0.18	0.12	0.13	-0.14	0.17	0.34	1

++ Large effect size (r > 0.8), +Moderate effect size (r > 0.5), *p < 0.05

Figure 1. Significant correlations (p < 0.05) at baseline collection for 35 pregnant women



Baseline relationships between outcome measures

Among measurements undertaken within the first visit, moderate inverse relationships were identified for carotenoid reflective scores with mass (r = -0.48, 95% CI = -0.70, -0.18; $p < 0.001$) and volume (r = -0.50, 95% CI = -0.71, -0.20; $p < 0.001$) indicating those with greater body mass and volume had lower carotenoid reflective scores (Table 2, Figure 1). A small positive relationship was found for vegetable and fruit intake and carotenoid reflective score (r = 0.31, 95% CI = -0.03, 0.58; p = 0.02). Gestation had a moderate, positive relationship with body mass (r = 0.55, 95% CI = 0.26, 0.75; $p < 0.001$) and volume (r = 0.55, 95% CI = 0.26, 0.74; $p < 0.001$).

Difference between outcome measures at baseline and visit II

Vegetable and fruit intake, body volume and body mass had all increased significantly by the second visit compared to baseline measures ($p < 0.05$; Table 3). Intra-individual carotenoid reflective scores did not change between the visits ($p > 0.05$).

Table 3. Mean ± SD at visit I (baseline) and visit II and *p*-value outputs from 1-tailed paired two sample *t*-test (*n* = 14)

	Baseline visit	Visit II	p-value
Carotenoid reflective score	366 ± 91	366 ± 102	0.50
Vegetable and fruit intake (serve/day)	5 ± 2	6 ± 2	0.04*
Carotenoid food intake (serve/day)	1 ± 1	1 ± 1	0.16
Body mass (kg)	69.1 ± 17.8	73.0 ± 17.1	< 0.001*
Body volume (l)	71.4 ± 18.4	74.6 ± 18.0	< 0.001*
Body density (kg.l^{-1})	0.97 ± 0.03	0.98 ± 0.01	0.09

*p < 0.05

Relationships between repeated outcome measures

For the 14 women with repeated measures (53 sessions in total), gestation had a large positive relationship with body mass (r_{rm} = 0.86, 95% CI = 0.66, 0.94; $p < 0.001$) and body volume (r_{rm} = 0.92, 95% CI = 0.80, 0.97; $p < 0.001$; Table 4). Women were also found to increase their vegetable and fruit intake as pregnancy progressed (r_{rm} = 0.60, 95% CI = 0.20, 0.83; p = 0.01).

Unlike baseline findings, the carotenoid reflective score was not found to be correlated with the self-reports of vegetable and fruit intake when repeated measures were considered (r_{rm} = -0.14, 95% CI = -0.56, 0.33; p = 0.56). Moderate and small, non-significant correlations were found between carotenoid reflective scores and increased gestation (r_{rm} = -0.29, 95% CI = -0.66, 0.19; p = 0.22), increased body mass (r_{rm} = -0.13, 95% CI = -0.55, 0.34; p = 0.59) and increased body volume (r_{rm} = -0.33, 95% CI = -0.68, 0.15; p = 0.17).

DISCUSSION

All women reported that the measurements were acceptable in the research setting for this pilot/feasibility study. Similar to the general population, the women in the study consumed substantially fewer servings and a smaller variety of vegetables and fruit than recommended in guidelines (Curran-Cournane & Rush, 2021). Only one serve of a carotenoid-rich food was consumed on average each day with a range of 0 to 3. The carotenoid reflection score of five women (14%) was below the lower cut-point for health (Rush et al., 2020). A review of prospective cohort studies and population-based, case-control studies of health outcomes in relation to plasma carotenoids stated that protection from cardio-metabolic diseases and cancer was when plasma carotenoids were > 2.5 μM which is equivalent to a Veggie Meter™ score of 450 (Donaldson, 2011). Overall, the consensus is that the more vegetables and fruit eaten, the lower the risk of diet-related, non-communicable disease (Halvorsen et al., 2021). Specifically for carotenoid concentrations a high intake of a variety of vegetables and fruits is advised (Böhm et al., 2021).

Body mass gain averaged 4 kg or 5.5% over eight weeks. There was an increase in the quantity and variety of vegetables and fruit consumed during this time for the 14 women with repeated measures; however, there was no measurable change in carotenoid concentration.

The inverse relationship of the carotenoid reflection score with body mass has been previously reported in non-pregnant populations (Rush et al., 2020) and supports the recommendation for increased quantities and variety of vegetables and fruit intake for those with an increased body mass. The finding that those who have a bigger mass require more carotenoid intake through vegetables and fruit aligns with previous research which found intake of essential nutrients should be in proportion to body size (Rush et al., 2020).

It is of concern that dietary guidelines do not currently reference the need for larger-bodied people to consume more foods or specific nutrients than smaller-bodied people (Ministry of Health, 2020). These findings provide an early indication that this may also apply to pregnant women. The only nutrient reference value that is based on body size is that for energy intake (National Health and Medical Research Council, 2006). Yet, for vitamin A which includes precursor carotenoids, 37% more is recommended for lactating women than for non-pregnant or pregnant women. Findings from the current study contribute to the understanding that the "dose" of vegetables and fruit needs to be increased relative to body size to

Table 4. Repeated measures correlation (rrm) matrix for 35 pregnant women across 53 sessions

	Gestation	Carotenoid reflective score	Vegetable and fruit intake	Carotenoid food intake	Body mass	Body volume	Body density
Gestation	1						
Carotenoid reflective score	-0.29	1					
Vegetable and fruit intake	0.60++*	-0.14	1				
Carotenoid food intake	0.36+	-0.16	0.50++*	1			
Body mass	0.85++*	-0.13	0.36+	0.36+	1		
Body volume	0.92++*	-0.33+	0.54++*	0.45+	0.87++*	1	
Body density	0.14	0.29	-0.24	-0.08	0.51	0.02	1

++ Large effect size (r > 0.5), +Moderate effect size (r > 0.3), *p < 0.05

maintain carotenoid reflective scores, although further research is required to determine if this confers a physiological benefit during pregnancy. It is important to note this recommendation places emphasis on increased nutrient-dense, not energy-dense, food.

During pregnancy, carotenoids may play important roles in fetal eye health and brain development (Prihastyanti et al., 2021) and in the prevention of preterm birth and intrauterine growth restriction (Zielińska et al., 2017). More research is needed to establish normal ranges for pregnancy at different gestations. Although several dietary sources such as eggs, dairy, liver and supplements can contribute to carotenoid concentrations in the body, vegetables and fruit account for an overwhelming majority of 80-90%. The current study findings demonstrate the dilution effects of increases in body mass and volume on carotenoid concentration, and may indicate that a higher intake of vegetables and fruits exceeding current recommendations is warranted. Further work may support the development of more specific guidelines for women regarding the quantity and variety of nutrient-rich food such as vegetables and fruit needing to be consumed throughout pregnancy.

It is difficult to make dietary recommendations when the cost of vegetables and fruits is increasing, as is the cost of living. Most people know that it is beneficial to consume vegetables and fruit, and in pregnancy women want to do what is best for their child but unfortunately the realisation of this has several barriers. Food insecurity in New Zealand continues to increase. New Zealand is a country that produces high-quality nutritious foods but mainly for export. Although our findings suggest the need for increased intake of vegetables and fruit during pregnancy, we recognise the challenges that accompany this recommendation.

STRENGTHS AND LIMITATIONS

This non-blinded study was an opportunity for pregnant women to understand more about their vegetable and fruit intake. When women presented again for further measurements there was an opportunity to see if their score had improved which would provide positive feedback on behaviour change. We have demonstrated that the Veggie Meter™ is able to be used to measure carotenoid status in pregnant women. An extensive literature search has not shown any other studies using this instrument during pregnancy.

Due to the nature of the study as a pilot/feasibility study, the cohort was small (n = 35) and, although beneficial for initial insights into this area of research, should be expanded for future research. The women recruited to this study were at different stages of pregnancy and therefore had different metabolic needs, so the cross-sectional analysis is a broad overview of carotenoid status in pregnancy. We do not know if the half-life of carotenoids changes with the progression of pregnancy and increased metabolic demands for nutrients. The retrospectively self-reported vegetable and fruit intake may lack accuracy.

FUTURE WORK

The first 1,000 days of life, including pregnancy, are recognised as a critical time of growth and development. Midwives are in a unique position to be able to communicate with whānau (Wong Soon et al., 2021). There is a rise in community initiatives to address food insecurity, including community gardens, reduction of food waste and sharing food. There are initiatives for school children, including fruit in schools and free school lunches (Curran-Cournane & Rush, 2021). Future work could include education/workshops or e-learning for midwives about how to increase vegetable and fruit intake as pregnancy progresses and a funded vegetable prescription for pregnant and lactating women. This area would benefit from further studies tracking women's body mass and volume, vegetable and fruit intake and carotenoid reflective scores for the duration of their pregnancy. To build on the knowledge gained in the current study, research which tightly controls for gestation is also warranted.

CONCLUSION

The current study found carotenoid reflective scores tended to be lower for those with greater body mass and volume; although women reported increasing their vegetable and fruit intake with increased gestation, their carotenoid reflective score did not increase. This study adds to the body of evidence that vegetable and fruit consumption in New Zealand is low and adds to the existing information that pregnant women are not consuming sufficient for optimal health. It is possible that vegetable and fruit intake should be increased to align with increases in body mass throughout pregnancy. Nourishing, whole foods should be accessible, available and in sufficient quantities for future-proofing for the next generation, who are reliant on the nutritional status of the pregnant woman for the best possible start for life-long health.

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The authors declare no conflict of interest. The funders had no role in the design of the study, in the collection, analyses or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

LANGUAGE STATEMENT

The terms woman/women/wahine/wāhine are used to refer to the pregnant and birthing person/people. This is to avoid confusion as the literature and the most recent Ministry of Health documents also use mother and woman (Ministry of Health, 2021). It is acknowledged that not all pregnant and birthing people identify as a woman or mother.

KEY POINTS

- Of 35 pregnant women assessed, only 25.7% met the guideline intake of 7+ vegetables and fruits a day.
- Lower carotenoid reflective scores were related to greater body mass and volume.
- It is recommended that the "dose" of vegetables and fruits be increased relative to body size.

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