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Vitamin D content of wild-caught traditional foods collected on Nyoongar Country in Western Australia

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ABSTRACT

Low vitamin D status and intake are prevalent among the Australian population, including Aboriginal and Torres Strait Islander peoples. We hypothesised that some traditional foods could contain vitamin D, and measured vitamin D in foods from Nyoongar Country, Western Australia. Samples of kangaroo, emu, squid/calamari and lobster/crayfish were collected and prepared by Aboriginal people using traditional and contemporary methods. We measured vitamin D_3, 25-hydroxyvitamin D_3 ($25(OH)D_3$), vitamin D_2 and $25(OH)D_2$ using liquid chromatography-triple quadrupole mass spectrometry. Kangaroo meat and offal were largely devoid of vitamin D (no mean values >0.1 μg/100 g). Vitamin D_3 was found in emu meat and calamari/squid (range 0.5–1.0 μg/100 g). No samples contained $25(OH)D_3$, vitamin D_2 or $25(OH)D_2$ at mean values >0.1 μg/100 g. Modern food composition data can complement traditional knowledges in the promotion of traditional foods for healthy eating and social and emotional wellbeing among Aboriginal and Torres Strait Islander peoples.

1. Introduction

Aboriginal and Torres Strait Islander peoples have used complex and sophisticated knowledges and systems to manage sustainable consumption of traditional foods for tens of thousands of years (Merne Altyerre-ipenhe (Food from the Creation time) Reference Group, Douglas, J., and Walsh, F, 2011). These extensive knowledges were founded and consolidated over generations to develop a rich, comprehensive and holistic understanding of the medicinal and nutritional benefits of foods and other substances that were hunted and gathered from land and waterways (Merne Altyerre-ipenhe (Food from the Creation time) Reference Group, Douglas, J., and Walsh, F, 2011).

From the late-18th century onwards, British colonial authorities dispossessed Aboriginal and Torres Strait Islander people of their land and Country (Ford & Roberts, 2022), preventing the practise of cultural lore, speaking traditional languages and accessing and connecting to

Abbreviations: 25(OH)D, 25-hydroxyvitamin D; AIATSIS, Australian Institute of Aboriginal and Torres Strait Islander Studies; EAR, Estimated Average Requirement; LC-QQQ, Liquid chromatography with triple quadrupole mass spectrometry; LOR, Limit of reporting; NHMRC, National Health and Medical Research Council; NMI, National Measurement Institute of Australia; PTAD, 4-Phenyl-1,2,4-triazoline-3,5-dione; RPD, Relative percent difference; SRM, Standard Reference Material.

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Country and traditional foods. Family and community units were forcibly broken apart and dispersed, often across hundreds to thousands of kilometres (National Inquiry into the Separation of Aboriginal and Torres Strait Islander Children from their Families (Australia), and Wilson, R, 1997). Among their many enduring impacts, these actions have disrupted the transmission of cultural knowledges to younger generations (Merne Altyerre-ipenhe (Food from the Creation time) Reference Group, Douglas, J., and Walsh, F, 2011). The loss of access to traditional land and nutritionally diverse traditional foods led to greater reliance on an industrialised diet that is typically more energy-dense and nutrient-poor compared to a traditional diet (Brimblecombe et al., 2014). As Aboriginal and Torres Strait Islander peoples strive to heal and repair cultural systems, there has been keen interest from Elders (highly respected custodians of cultural knowledges) and community leaders to combine traditional scientific knowledges of food with Western science to encourage younger community members to embrace greater consumption of traditional foods (Elders' consultation, personal communication, 2021).

Low vitamin D status is prevalent across the whole Australian population and 27 % of Aboriginal and Torres Strait Islander adults have serum 25-hydroxyvitamin D (25(OH)D) concentration < 50 nmol/L, with a higher prevalence (39 %) among adults living in remote areas (Black et al., 2020). This indicates that many do not generate sufficient vitamin D through sun exposure, while there is low uptake of vitamin D supplements and low intake of vitamin D from food (Dunlop et al., 2022; Neo et al., 2025). This is concerning due to the links between vitamin D and health conditions that are prevalent among Aboriginal and Torres Strait Islander people, such as type 2 diabetes and cardiovascular diseases (Australian Bureau of Statistics, 2014; Liu et al., 2022).

Internationally, there is a paucity of data on the vitamin D content of traditional foods. In 2006, the vitamin D_3 content of 16 sea mammal, land animal and seafood species collected by First Nations peoples in the Canadian Arctic was published (Kuhnlein et al., 2006). In that study, several samples contained substantial concentrations of vitamin D_3, including some fish and shellfish products, and blubber, oil and liver from some sea mammals (Kuhnlein et al., 2006). Our team's prior research has generated data on the vitamin D_3, 25(OH)D_3, vitamin D_2 and 25(OH)D_2 content of camel, crocodile, kangaroo, and emu products purchased commercially in Australia (Dunlop et al., 2021; Dunlop et al., 2022). Crocodile and emu products contained some vitamin D_3 and lower concentrations of 25(OH)D_3 as expected, while we discovered a 25(OH)D_3-dominated profile in camel products (Dunlop et al. 2022). Kangaroo samples, on the other hand, contained little to no vitamin D (Dunlop et al., 2021; Dunlop et al., 2022). To our knowledge, there otherwise remains a worldwide lack of data on the vitamin D content of traditional foods, especially for foods collected from the wild and prepared by First Nations peoples, and for all four key dietary forms of vitamin D (vitamin D_3, 25(OH)D_3, vitamin D_2 and 25(OH)D_2).

The identification of traditional food sources of vitamin D that are readily available on Country could support improved vitamin D intake and status among Aboriginal and Torres Strait Islander peoples. However, very little is known about the vitamin D content of traditional foods in Australia, and composition data for foods of interest to Aboriginal people are needed. Hence, the aim of this study was to measure the vitamin D content of traditional foods selected and collected by Aboriginal people on Nyoongar Country, including Boorloo (Perth city) and its surrounding regions in south-western Western Australia. We hypothesised that some traditional foods could be useful sources of vitamin D.

2. Methods

The *Vitamin D in Bush Tucker* project was a collaboration between Aboriginal Elders and researchers from Deakin University, The Kids Research Institute Australia, Curtin University and the National Measurement Institute. Its aims included the collection of traditional foods and measurement of their vitamin D content. Ethical approval for this study was granted by the Western Australian Aboriginal Health Ethics Committee (HREC979). The Western Australian Aboriginal Health Ethics Committee (Aboriginal Health Council of Western Australia, 2022) requires that research is conducted in accordance with specific guidelines, including, but not limited to, those of the National Health and Medical Research Council (National Health and Medical Research Council, 2018) and the Australian Institute of Aboriginal and Torres Strait Islander Studies (Australian Institute of Aboriginal and Torres Strait Islander Studies, 2020). Those guidelines set out principles to ensure that research is safe, respectful, responsible, high quality, of benefit to Aboriginal and Torres Strait Islander people and communities, and that the rights of Aboriginal and Torres Strait Islander people are recognised and respected. Some of the data generated by this project have been aggregated or generalised for the purposes of reporting in order to protect the Indigenous Cultural and Intellectual Property (Australian Government, 2025) of the people of the Nyoongar Nation. The contributions of Elders have been incorporated respectfully, and with consent, into the analysis and reporting.

2.1. Sample selection and collection

The Nyoongar Nation is one of the largest Aboriginal nations in Australia. Its people (n $\sim$ 40,000) are the traditional owners and custodians of $\sim$ 200,000 km^2 of unceded lands and waterways on Nyoongar Country (Fig. 1) in south-western Western Australia (South West Aboriginal Land and Sea Council, 2025). In addition to foods purchased from retail outlets, Nyoongar people may include in their diets a variety of traditional foods, including plant, land, river and sea foods (South West Aboriginal Land and Sea Council, 2025). Elders identified animal foods that have been included in traditional and contemporary diets, and that were of interest to community members in terms of their vitamin D content, namely: red kangaroo (Nyoongar name, *marloo*; scientific name, *Macropus rufus*); Euro kangaroo (Nyoongar name, *yongka*; scientific name, *Macropus robustus*) meat; emu (Nyoongar name, *wetj*; scientific name, *Dromaius novaehollandiae*) meat; Southern calamari/squid (Nyoongar name, *biyabeda*; scientific name, *Septioteuthis australis*) and Western Australian rock lobster/crayfish (Nyoongar name, *maron*; scientific name, *Panulirus cygnus*). From 2021 to 2024, samples of the aforementioned foods were donated by Aboriginal people for measurement of their nutrient content (Table 1, Fig. 2). Samples were donated as portions of foods collected during the normal hunting and gathering activities conducted by people providing for themselves and their families.

The person providing the sample completed a sample collection form that detailed when, where and by what method the sample was collected, along with the traditional and common names of the species collected. Data on the number of plants/animals included in the sample, the total weight, any inedible parts and any preparative treatment carried out were also collected. Both raw and cooked samples were collected. Where cooked samples were included, individual pieces within the total raw sample were halved to provide two comparable samples, one of which was analysed raw and the other cooked. Cooked samples were cooked as they would typically be prepared for consumption (using traditional or contemporary methods), with details of the preparation and cooking process recorded. Immediately after collection and preparation, samples were photographed where possible, then wrapped in foil and sealed within ziplock bags to limit exposure to air and light, thus minimising loss of moisture and degradation of volatile nutrients. Where available, samples of roughly equal mass from multiple animals were packaged together for composite analysis. Samples taken from a single animal only were packaged separately for individual analysis. Samples were frozen at -18 °C within 24 h of collection.

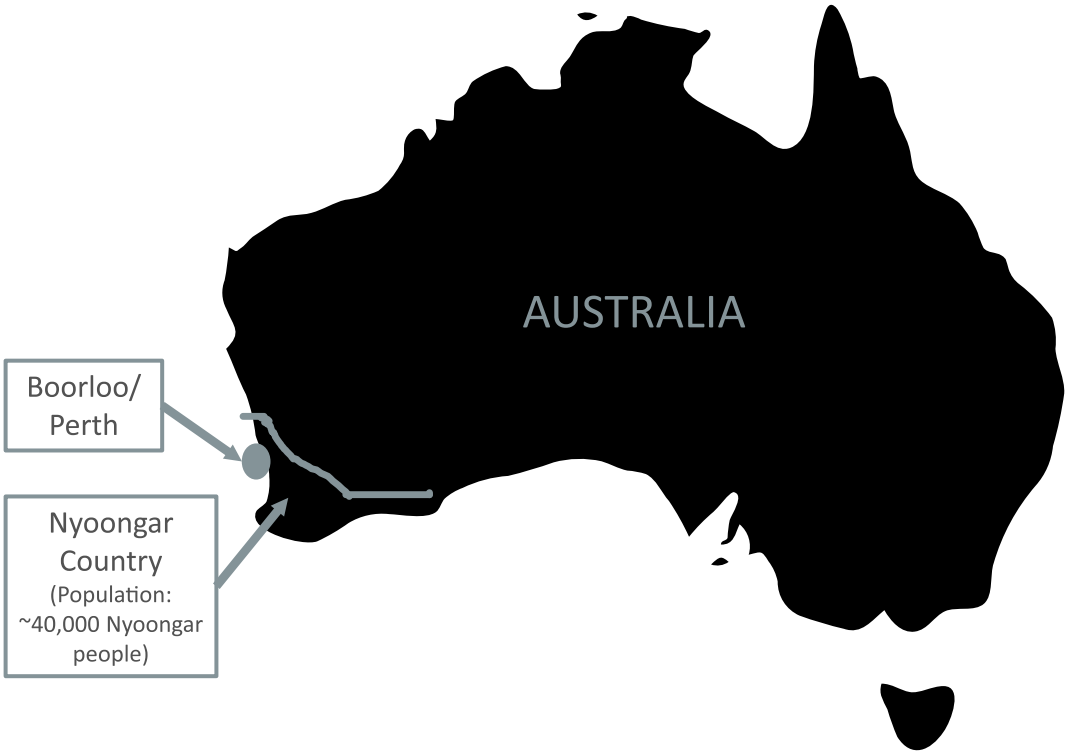

Fig. 1. An approximate depiction of Nyoongar Country.

2.2. Sample transport and analysis

Samples were couriered overnight in insulated containers filled with dry ice from Perth, Western Australia to the National Measurement Institute's laboratory in Port Melbourne, Victoria. For each sample line listed in Table 1, some of which contained samples from multiple animals, the entire sample was homogenised and aliquots were removed for analysis. All analyses were duplicated. Fat and moisture were measured using the Soxhlet extraction method (Food Science Australia, 1998) and an in-house process based on a previously published AOAC method (AOAC International, 2005), respectively.

Vitamin D_3, 25(OH)D_3, vitamin D_2 and 25(OH)D_2 were measured using a liquid chromatography with triple quadrupole mass spectrometry (LC-QQQ) method that has been described in detail previously (Dunlop et al., 2017; Dunlop et al., 2021; Dunlop et al., 2022; Hughes et al., 2018). Briefly, an amount of sample that would yield $\leq$ 1 g saponified fat was combined with a known quantity of chemically labelled internal standard, 1 g sodium ascorbate, 10 mL deionized water, 30 mL ethanol, 2 g potassium hydroxide, and deionized water to make up to 50 mL in a capped 50 mL Falcon® tube. The Falcon® tube was placed in a shaker bath overnight. After hydrolysis in an ethanolic potassium hydroxide solution, vitamin D analytes were extracted to diatomaceous earth solid phase extraction tubes (Chem Elut™ 10 mL unbuffered SPE cartridges, Agilent Technologies, Santa Clara, USA) and washed through with petroleum ether. The washes were evaporated to dryness under nitrogen gas, then the residues were resolvated into heptane and evaporated again to dryness under nitrogen gas. The resulting residue was resolvated into 4-Phenyl-1,2,4-triazoline-3,5-dione (PTAD) in anhydrous acetonitrile for derivatisation, which was stopped after 10 min by addition of water.

Vitamin D analytes were isolated on a reverse phase C18 column (Supelco Ascentis® Express C18, 15 cm × 3 mm, 2.7 µm [Cat#53816-U], Sigma-Aldrich, St. Louis, USA). They, and a range of calibration samples, were analysed by LC-QQQ using a 1290 Infinity Series LC System and 6460 Triple Quad LC-MS system (Agilent Technologies, Santa Clara, USA), configured in electrospray ionization mode with positive polarity. The calibration curve generated from calibration sample analysis was used to quantitate analyte concentrations.

2.3. Quality assurance

One sample from each analysis run was chosen randomly and spiked with a known concentration (µg/100 g of sample matrix) of each D-vitamer. One sample of an in-house control sample (infant formula and freeze-dried irradiated mushroom powder) was also analysed. The percentage of the known concentration recovered in spiked and control samples was reported. All analyses were duplicated, which included duplication of the process from saponification to quantitation for D vitamers. The relative percent difference (RPD) between duplicate analyses was calculated as (difference between replicate values/average of replicates) x 100. The limit of reporting (LOR) was 0.1 µg/100 g for all D vitamers.

2.4. Data handling

Values for single composite samples are presented as the mean of duplicated analyses. Values derived from multiple composite samples are presented as the mean of duplicated analyses ± standard deviation (SD). Results reported as < LOR were treated as zero for the purpose of calculating standard deviation.

3. Results

The percent recovery in spiked samples ranged from 76 to 89 % and was 101 % for the control sample. The mean RPD for vitamin D_3 was 11 %.

Vitamin D_3 was quantified in 6 of 15 composite samples, namely all emu and calamari/squid samples (Table 2). Vitamin D_2 was quantified at a value equal to the LOR in one analysis of one kangaroo offal sample only, but as the paired replicate value was < LOR, the mean of replicates was assumed as < LOR. Kangaroo meat and offal samples were otherwise devoid of D vitamers. No samples contained 25(OH)D_3 or 25(OH)

Table 1
Characteristics of samples collected on Nyoongar Country in Western Australia for measurement of vitamin D_3, 25-hydroxyvitamin D_3 (25(OH)D_3), vitamin D_2 and 25(OH)D_2.

Traditional Nyoongar name	Western common name	Scientific name	Sample	Animals per analytical sample	Male/ female animal	Collection	Location	Sample weight (g)	Preparation method
Land species									
Marloo	Red kangaroo	*Macropus rufus*	Tail, cooked	1	Male	September 2021	Inland regional WA	525	Singed hair off in the fire, wrapped in paper, wet paper, buried paper-wrapped tail and covered with coals
Marloo	Red kangaroo	*Macropus rufus*	Rump, raw	2	Both	September 2021	Inland regional WA	452	Fileted
Marloo	Red kangaroo	*Macropus rufus*	Rump, cooked	2	Both	September 2021	Inland regional WA	452	Barbecued without oil or seasoning
Marloo wer yongka	Red kangaroo and Euro kangaroo	*Macropus rufus* and *Macropus robustus*	Heart, raw	6	Unknown	April 2023	Inland regional WA	520	–
Marloo wer yongka	Red kangaroo and Euro kangaroo	*Macropus rufus* and *Macropus robustus*	Liver, raw	6	Unknown	April 2023	Inland regional WA	503	–
Marloo wer yongka	Red kangaroo and Euro kangaroo	*Macropus rufus* and *Macropus robustus*	Liver, cooked	6	Unknown	April 2023	Inland regional WA	494	Pan fried to medium rare without oil or seasoning
Marloo wer yongka	Red kangaroo and Euro kangaroo	*Macropus rufus* and *Macropus robustus*	Offal (liver, heart, kidney), raw	6	Unknown	April 2023	Inland regional WA	580	–
Marloo wer yongka	Red kangaroo and Euro kangaroo	*Macropus rufus* and *Macropus robustus*	Offal (liver, heart, kidney), cooked	6	Unknown	April 2023	Inland regional WA	550	Pan fried to medium rare without oil or seasoning
Wetj	Emu	*Dromaius novaehollandiae*	Rump/top leg, raw	1	Unknown	October 2021	Inland regional WA	530	Skinned, deboned
Wetj	Emu	*Dromaius novaehollandiae*	Rump/top leg, cooked	1	Unknown	October 2021	Inland regional WA	540	Skinned, deboned, pan fried (medium heat) without oil or seasoning
Marine species									
Biyabeda	Southern calamari/ squid	*Sepioteuthis australis*	Tentacles and tube, raw	8	Both	September 2021	Coastal metropolitan Boorloo/Perth WA	516	Skinned, gutted
Biyabeda	Southern calamari/ squid	*Sepioteuthis australis*	Tentacles and tube, cooked	8	Both	September 2021	Coastal metropolitan Boorloo/Perth WA	525	Skinned, gutted, sliced, pan fried (high heat) without oil or seasoning
Maron	Western Australian rock lobster/ crayfish	*Panulirus cygnus*	Tail, raw	2	Both	September 2021	Coastal metropolitan Boorloo/Perth WA	525	Peeled
Maron	Western Australian rock lobster/ crayfish	*Panulirus cygnus*	Legs and tails, cooked	8	Both	September 2021	Coastal metropolitan Boorloo/Perth WA	508	Steamed for 15 min, then peeled

WA, Western Australia.
Samples collected in September–October 2021 were analysed in November 2021. Samples collected in June 2022 and April 2023 were analysed in October 2023.

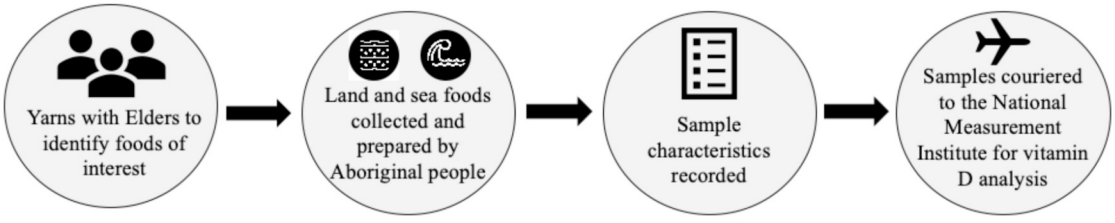

Fig. 2. Sample selection, collection and analysis.

D_2 at a concentration ≥ LOR.

4. Discussion

We measured four D vitamers in wild-caught kangaroo, emu and seafood products. The data generated extend our understanding of

Table 2
Moisture, fat, vitamin D_3, 25-hydroxyvitamin D_3 (25(OH)D_3), vitamin D_2 and 25(OH)D_2 content of traditional foods collected on Nyoongar Country in Western Australia.

Traditional Nyoongar name	Western common name	Scientific name	Sample	Animals included in the sample (*n*)	Composite analytical samples (*n*)	Moisture (g/100 g)	Fat (g/100 g)	Vitamin D_3 (μg/100 g)	25 (OH) D_3 (μg/100 g)	Vitamin D_2 (μg/100 g)	25 (OH) D_2 (μg/100 g)
Raw											
Kangaroo meat											
Marloo	Red kangaroo	*Macropus rufus*	Rump	2	1	73.5	3.2	<0.1	<0.1	<0.1	<0.1
Kangaroo offal											
Marloo wer yongka	Red kangaroo and Euro kangaroo	*Macropus rufus* and *Macropus robustus*	Offal (heart, liver, kidney)	18	3	75.55 ± 3.3	2.5 ± 0.9	<0.1[a]	<0.1	<0.1	<0.1
Emu products											
Wetj	Emu	*Dromaius novaehollandiae*	Rump/top leg	1	1	66.1	17.2	0.5	<0.1	<0.1	<0.1
Seafood											
Biyabeda wer maron	Western Australian rock lobster/ crayfish and Southern calamari/ squid	*Panulirus cygnus* and *Sepioteuthis australis*	Tentacle, tube and tail	10	2	76.1 ± 2.9	1.2 ± 0.5	0.5 ± 0.7	<0.1	<0.1	<0.1
Cooked											
Kangaroo meat											
Marloo	Red kangaroo	*Macropus rufus*	Tail and rump	3	2	67.6 ± 2.0	3.6 ± 2.0	<0.1	<0.1	<0.1	<0.1
Kangaroo offal											
Marloo wer yongka	Red kangaroo and Euro kangaroo	*Macropus rufus* and *Macropus robustus*	Offal (heart, liver, kidney)	12	2	69.8 ± 0.3	5.5 ± 2.2	<0.1	<0.1	<0.1[a]	<0.1
Emu meat											
Wetj	Emu		Rump/top leg	1	1	67.3	4.1	0.8	<0.1	<0.1	<0.1
Seafood											
Biyabeda wer maron	Western Australian rock lobster/ crayfish and Southern calamari/ squid	*Panulirus cygnus* and *Sepioteuthis australis*	Tentacle, tube and tail	16	2	74.2 ± 1.2	1.3 ± 0.5	0.5 ± 0.7	<0.1	<0.1	<0.1

All analyses were duplicated. Values for single composite samples are presented as the mean of duplicated analyses. Values derived from multiple composite samples are presented as the mean of duplicated analyses ± standard deviation.
Limit of reporting = 0.1 μg/100 g for all D vitamers. Values <0.1 were treated as zero for the purpose of calculating standard deviation.
[a] The vitamer was quantified at the value of the LOR in one replicate analysis, but the mean value of multiple composite samples was <LOR.

vitamin D in foods available in Australia and particularly add to the very limited vitamin D composition data for traditional foods globally.

This study builds on our previous work in which we measured vitamin D in kangaroo meat and seafood purchased at retail outlets (Dunlop et al., 2021), and in kangaroo meat purchased from a central supplier and emu products purchased from emu farms (Dunlop et al., 2022). In those earlier studies, samples were prepared either using contemporary methods only (Dunlop et al., 2021) or analysed raw (Dunlop et al., 2022). In this study, samples were prepared as they would be by Nyoongar people in the present day, using a modern-day blend of traditional and contemporary methods. Some samples were also halved to provide a raw and cooked sample – for the first time, this provides valuable insight into the changes that occur in vitamin D content and profile in these foods upon cooking.

The data from this study confirm our earlier findings (Dunlop et al., 2021; Dunlop et al., 2022) that, unlike the meat of many other animals, kangaroo meat is not a source of vitamin D. Vitamin D composition data shown for kangaroo in the Australian Food Composition Database – Release 2.0 (Food Standards Australia New Zealand, 2019) were based on the earlier assumption that the vitamin D profile of kangaroo meat was similar to that of other animals. Hence, in the absence of analytical vitamin D data for kangaroo meat, values had been based on pooled data for other meats (beef, lamb, pork and chicken) (Food Standards Australia New Zealand, 2016, 2019).

Our earlier studies (Dunlop et al., 2021; Dunlop et al., 2022) were of samples of wild-caught kangaroo meat sourced from the eastern states of Australia and purchased from commercial retailers. While trace amounts of vitamin D_2 and 25(OH)D_2 were detected in those earlier samples (Dunlop et al., 2021; Dunlop et al., 2022), neither vitamer was detected in samples collected on Nyoongar Country for our present study. Following our initial studies that showed kangaroo meat was not a source of vitamin D (Dunlop et al., 2021; Dunlop et al., 2022), we had hypothesised that vitamin D may be present in kangaroo offal, such as the liver and kidneys, based on earlier studies of the vitamin D content of organ meats from cows, sheep and chickens (Dunlop et al., 2021; Schmid & Walther, 2013). To our knowledge, this study has provided the first published data on four D vitamers in kangaroo offal, demonstrating that it, like kangaroo muscle meat, is largely devoid of vitamin D.

We are unaware of any published data on circulating 25(OH)D concentration in kangaroos; however, low circulating concentrations of

25(OH)D have been reported for other marsupials, namely wombats and brushtail possums (Fowler & Fraser, 1993). It has been speculated that the vitamin D requirement of the koala, another marsupial, may be low (Pye et al., 2013). It does not yet appear to be known whether or why the circulating levels and/or requirement of vitamin D in kangaroos may be different to non-marsupial animals. While it is useful to know that they are not a source of vitamin D, kangaroo products are lean sources of protein and many other key nutrients (Food Standards Australia New Zealand, 2019). Importantly, kangaroos are a culturally important element of a traditional diet; they are freely available to people in and around metropolitan, rural and remote areas alike, making them an accessible and sustainable food source.

Our finding that raw wild-caught emu meat contained some vitamin D_3 was in line with our earlier results for six samples of farmed emu meat, for which the mean (± SD) for vitamin D_3 equalled 0.88 ± 0.18 μg/100 g (Dunlop et al., 2022). The wild-caught sample from this study contained no detectable concentration of 25(OH)D_3 and, similarly, we previously detected only trace amounts (<0.1 μg/100 g) in farmed emu meat (Dunlop et al., 2022). The wild-caught samples of emu meat from our current study did not contain quantifiable concentrations of vitamin D_2, while the farmed samples from our previous study contained a relatively low concentration 0.13 ± 0.03 μg/100 g (Dunlop et al., 2022). Emus, whether farmed (usually in large, outdoor areas) or wild, will feed opportunistically on a diverse range of foods of plant, insect and animal origin. The vitamin D content of their products could vary depending on the types of foods they have consumed; however, the single sample of wild-caught emu meat available for analysis in this study was not sufficient to examine any differences in content between wild and farmed emu.

We were able to add analysis of D vitamers in comparable raw and cooked samples of emu meat; however, we were unable to determine the true retention of the D vitamers. To our knowledge, there is only one other published study of the vitamin D composition of emu meat. In that study, conducted in Canada, vitamin D was neither detected in raw emu thigh or leg meat nor in emu jerky; however, the limit of detection for the method was 2.1 μg/100 g (Pegg, Amarowicz, & Code, 2006). Details of emu farming/feeding methods were not reported in the Canadian study (Pegg et al., 2006). Therefore, it remains unclear whether the difference in the findings between that study and our present study could have been related to the differences in foods consumed by the emus, or if similarities were masked by the limit of detection of the method used in the Canadian study being higher than the concentration of vitamin D_3 that we found in cooked emu meat. Studies of a larger number of wild-caught samples could improve our knowledge of any variation in the vitamin D composition between wild and farmed, and raw and cooked, emu products.

Our findings for the content and D vitamer profile of squid/calamari were in agreement with those determined for crumbed calamari or squid for our earlier study of retail foods available in Australia (Dunlop et al., 2021). In the present study, there was no difference in content or D vitamer profile between comparable raw and cooked samples. We are not aware of any other Australian data for the vitamin D content of lobster/crayfish; however, the findings of our present study are in line with values of zero reported in the Danish food composition database (National Food Institute & Technical University of Denmark, 2024) and the USDA's FoodData Central Database (U.S. Department of Agriculture, 2019).

Through this study, we have expanded our very limited understanding of the vitamin D content of foods that may be included in a traditional Aboriginal and Torres Strait Islander diet. We found that wild-caught emu meat and squid/calamari contain small amounts of vitamin D that would contribute cumulatively with other minor food sources. While no foods included in this study contained substantial amounts of vitamin D, they are all potential components of a diverse and nutrient-rich diet. Notwithstanding nutrient content, there are many other benefits to consuming traditional foods. Consumption of traditional foods commonly involves activities relating to the hunting or gathering of foods – physical activities that promote good health and fitness. These activities are often conducted alongside other community members, providing an opportunity to connect with family, community, culture and Country, which are crucial contributors to the holistic health of Indigenous populations (Calma, Dudgeon, & Bray, 2017).

Furthermore, the foods included in this study were wild-caught foods that have been consumed sustainably by generations of Australian First Nations peoples. Consumption of these foods does not rely on complex and environmentally detrimental food production systems. Promoting consumption of traditional foods could support more diverse and sustainable food consumption patterns, in line with climate change mitigation recommendations (Willett et al., 2019). Therefore, the building of comprehensive nutrient composition data for traditional foods is a worthwhile endeavour for use alongside long-standing traditional knowledges in the promotion of traditional foods.

A major strength of this study was that sample selection and collection were led and driven by Aboriginal Elders and community members, providing data that are of use to the community and that complement the extensive traditional knowledges already held for these foods. The project was co-developed and co-led by Aboriginal Elders, Aboriginal researchers and Wadjela (non-Aboriginal) researchers and involved a rich multi-way learning process. For the first time, four D vitamers have been measured in traditional foods collected and prepared by Aboriginal people using traditional and contemporary collection and cooking methods. For kangaroo and seafood species, samples were taken from multiple animals in order to capture any variation between animals. Another major strength of the study was the use of a sensitive and specific method to measure four D vitamers in duplicate; data for all four vitamers in foods remain limited globally.

A limitation of the study was that composite, rather than individual, samples were analysed due to financial resource limitations – this precluded any investigation of the variation in vitamin D content between individual samples. It was beyond the scope of the study to assess any seasonal variation in these foods, and samples were generally collected at a single time point; however, samples were collected during the season/s that they are traditionally and sustainably consumed. While comparable raw and cooked samples were analysed, suitable pre- and post-cooking weights were not available to allow calculation of the true retention of vitamin D in those cooked samples. Emu meat was taken from one animal only; however, given the rarity of the opportunity to measure nutrients in a wild-caught sample, the data generated are a valuable addition to the overall data holdings for traditional foods. This highlights the challenges of acquiring traditional foods, both for consumption and scientific investigation. These challenges include, but are by no means limited to, the cost, logistics and safety of traveling to off-road and increasingly remote areas with no guarantee of encountering prey, particularly as animal habitats, food and water sources and population numbers dwindle due to urbanisation.

5. Conclusions

We measured vitamin D in wild-caught kangaroo, emu and seafood samples. For the first time, we developed vitamin D composition data for four D vitamers in foods collected and prepared by Aboriginal people using a blend of traditional and contemporary methods. Identifying the traditional food sources of key nutrients provides useful data that can be used to complement complex and sophisticated traditional knowledges in the promotion of nutrient-rich traditional foods. Greater consumption of traditional foods and their displacement of more energy-dense and nutrient-poor Western foods could be of great benefit to the health and social and emotional wellbeing of Aboriginal and Torres Strait Islander people. Comprehensive composition data are needed for the macro- and micronutrient content of traditional foods. Vitamin D should also be measured in other traditional foods to identify sources of this important nutrient.

Chemical compounds studied in this article

Vitamin D_3/cholecalciferol (PubChem CID: 5280795) Vitamin D_2/ergocalciferol (PubChem CID: 5280793) 25-hydroxyvitamin D_3/25-hydroxycholecalciferol (PubChem CID: 5283731) 25-hydroxyvitamin D_2/25-hydroxyergocalciferol (PubChem CID: 5710148)

CRediT authorship contribution statement

Eleanor Dunlop: Writing – original draft, Project administration, Methodology, Data curation. **Noel Nannup:** Writing – review & editing, Resources, Methodology, Funding acquisition, Conceptualization. **Dale Tilbrook:** Writing – review & editing, Resources, Methodology, Funding acquisition, Conceptualization. **Carol Michie:** Writing – review & editing, Project administration, Methodology. **Cindy Prior:** Writing – review & editing, Methodology. **Greg Nannup:** Writing – review & editing, Resources, Methodology. **Alison Nannup:** Writing – review & editing, Resources. **Brad Farrant:** Writing – review & editing, Funding acquisition, Conceptualization. **Judy Cunningham:** Writing – review & editing, Methodology, Funding acquisition, Data curation, Conceptualization. **Paul Adorno:** Writing – review & editing, Resources, Methodology, Funding acquisition. **Georgios Dabos:** Writing – review & editing, Investigation. **John Jacky:** Writing – review & editing, Methodology. **Theoni Whyman:** Writing – review & editing. **Janine McNamara:** Writing – review & editing, Methodology. **Liam Bedford:** Writing – review & editing, Methodology. **Carrington C.J. Shepherd:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Andrea Begley:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Belinda Neo:** Writing – review & editing. **Lucinda J. Black:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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