Journal of Food Measurement and Characterization
https://doi.org/10.1007/s11694-021-01182-4

ORIGINAL PAPER

Proximate composition, functional and antimicrobial properties of wild harvest *Terminalia carpentariae* fruit

Jiale Zhang[1] · Anh Dao Thi Phan[1] · Sukirtha Srivarathan[1] · Saleha Akter[1] · Yasmina Sultanbawa[1] · Daniel Cozzolino[1]

Received: 13 July 2021 / Accepted: 30 September 2021

Abstract

Terminalia hadleyana (subsp. carpentariae C. T. White) is native to Northern Australia where fruits of this plant have been used as a traditional food by the Australian Indigenous people. The aim of this study was to evaluate the morphology, chemical composition, functional (e.g. vitamin C, phenolic content) and antimicrobial properties of *T. carpentariae* fruits, harvested from the wild at full maturity. Variability has been observed in both fruit morphology (size and weight) and chemical composition. Proximate analysis showed that these fruits have high concentration of dietary fibre (DF) (51.2 g/100 gDW), and minerals such as K (1780 mg/100 g DW), Ca (373 mg/100 g DW) and Mg (150 mg/100 g DW). High levels of total phenolic content (TPC) (11,392 mg GAE/100 g DW) and vitamin C (11,046 mg/100 g DW) were also observed. Fruit extracts also showed inhibitory effects against the growth of foodborne microorganisms such as *Staphylococcus aureus*, methicillin resistant *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Shewanella putrefaciens*. Overall, these results contribute to provide with relevant information of the potential of *T. carpentariae* fruit as a functional ingredient to the Australian Indigenous communities and the emerging Australian native food industry.

Keywords *Terminalia carpentariae* · Phytochemicals · Hydrolysable tannins · Polyphenols · Antimicrobial activity · Antioxidant · Wild harvested

Introduction

The genus *Terminalia* comprises of more than 250 species, and it is the second-largest genus in the family Combretaceae [1]. Plants from the genus *Terminalia* are mainly distributed in tropical and subtropical regions of America, Australia, Asia, and Africa [2, 3]. More than 30 species or subspecies grow in Australia, including the well-known *Terminalia ferdinandiana* (commonly known as Kakadu plum) [4]. Both fruits and leaves of *T. ferdinandiana* have been reported to possess strongest radical scavenging activity and the highest levels of antioxidant compounds compared with other native fruits found in Australia [5].

Terminalia hadleyana (subsp. *carpentariae* C. T. White), belongs to the family Combretaceae, popularly known as wild peach, and is native to Northern Australia [6]. This plant is a shrub or small tree with mottled yellow, grey or orange bark up to 10 m high [6]. The cambium layer of *T. carpentariae* contains a series of bioactive phytocompounds, including saponins, tannins, flavonoids, and triterpenoids exerting antioxidant and antimicrobial activities [7]. More than 20 compounds have been identified in the leaf of *T. carpentariae* exhibiting high inhibitory effects against *Bacillus anthracis* [8]. Most of the plants of the genus *Terminalia* have a long history of usage in medicinal applications worldwide [1] where several bioactive phytochemicals (> 300) have been found [9]. Pharmacological studies have reported the importance of these bioactive phytochemicals in liver and kidney protection [10–13], and having antibacterial [14], antifungal [15, 16], antiparasitic [17], anti-inflammatory [18, 19], and anti-obesity activities [20, 27]. Among these bioactive compounds, tannins, including ellagitannins, gallotannins, dimeric- and trimeric tannins were reported as the main bioactive compounds in most of the *Terminalia* species [9].

✉ Daniel Cozzolino
d.cozzolino@uq.edu.au

[1] The University of Queensland, ARC Industrial Transformation Training Centre for Uniquely Australian Foods, AND Centre for Nutrition and Food Sciences, Queensland Alliance for Agriculture and Food Innovation, St. Lucia, Brisbane, QLD 4072, Australia

Published online: 08 October 2021

In addition to tannins, vitamin C, a strong natural antioxidant, has been also documented as an important bioactive compound in many scientific studies of *Terminalia* [5, 21]. For example, fruits of *T. ferdinandiana* contain exceptional levels of vitamin C up to 22,000 mg/100 g DW [21]. The high concentration of this vitamin in fruits of *Terminalia* has been reported to be approximately 900-fold higher than blueberries where in oranges and grapefruits the concentration of this vitamin only reaches around 0.5% of the dry weight of the fruit [2, 22].

It has been also reported that different plant extracts (e.g. methanolic and water) of the genus *Terminalia* exhibited antimicrobial properties and consequently some of these species have been used in traditional medicine. Fruits of both *T. ferdinandiana* and *chebula* have been reported to exhibit antibacterial properties against both gram-positive and gram-negative bacteria [23, 24]. Other species of *Terminalia* such as *australis*, *brownii* and *mollis* have been also reported to exhibit high antifungal activity [25, 26].

Although, the fruits and other plant parts of this plant have been traditionally used as food or medicine by the Australian Indigenous people for thousands of years, limited scientific reports have been published on the composition, antioxidant and antimicrobial properties of *T. carpentariae* fruits. Besides, no research has been reported on the identification and quantification of phytochemicals of *T. carpentariae* fruits and their potential biological functions.

The aim of this study was to evaluate the morphology, chemical composition, functional (e.g. vitamin C, phenolic content) and antimicrobial properties of *T. carpentariae* fruits, harvested from the wild, at full maturity.

Materials and methods

Sample collection and processing

Fruit samples used in this study were harvested at full maturity in December 2019 from individual trees grown in the wild in East Arnhem Land (Northern Territory, Australia). Individual fruit samples were freeze-dried at − 48 °C for 72 hs (CSK Climatek, Darra, Queensland, Australia). Then, the pulp and seed of the fruit samples were manually separated, followed by milling the seedless pulp fruit samples into a fine powder using a mixer mill MM 400 (Retsch GmbH, Haan, Germany). Samples were stored at – 35 °C until further analysis.

Proximate and mineral analysis

Proximate and minerals analysis were performed in a commercial laboratory (Symbio Alliance Laboratories, Brisbane, QLD, Australia). Analysis were carried out using accredited in-house or standard AOAC methods. Crude protein (CP) was determined using AOAC method 990.03, total fat (TF) using AOAC method 991.36, ash using AOAC method 923.03. Saturated (SFA), monounsaturated (MFA), polyunsaturated (PUFA), trans fats (TFA), dietary fiber (DF) and carbohydrates (CHO) were determined using in-house methods (Symbio Alliance Laboratories, Australia), and minerals were determined by Inductively Coupled Plasma (ICP)—mass spectrometry. Moisture (M) content was determined according to AOAC method 934.01.

Morphology

Individual fruit samples (n = 100) were randomly selected and thawed at room temperature where the length and width were recorded using a 150 mm Digital Calliper (Craftright Engineering Works, Jiangsu, China). The weight of whole fruit, pulp and seeds, was recorded using a laboratory scale (Sartorius CP224S, Gottingen, Germany).

Determination of total soluble solids, pH and titratable acidity

The pulp of fruit samples (n = 20) was finely ground into a puree and diluted (1:10; w/v) with Milli-Q water (18 M Ω cm at 23 °C) (Millipore, USA). Centrifuged supernatant was retained for total soluble solid (TSS) measurement using an OPTi@ Digital Handheld Refractometer (Xylem, UK). The pH was recorded on the diluted puree using a pH meter (Metrohm, NSW, Australia). The titratable acidity (TA) was determined by titrating with 0.1 N NaOH using an automatic titration unit (Metrohm, NSW, Australia).

Extraction and analysis of bioactive compounds

Fruit bioactive compounds were extracted using an aqueous methanol 80% (v/v) solution. Freeze-dried fruit powder (approx. 2 g) samples were homogenized using 20 ml of 80% methanol, followed by sonication in an ultrasonic bath (Elma Schmidbauer GmbH, Ruiselede, Belgium) for 15 min. The tubes were continuously shaken on a reciprocating shaker (RP1812, Paton Scientific, Adelaide, SA, Australia) for another 15 min, followed by centrifuging the slurry at 3900 rpm for 10 min using Eppendorf 5180 centrifuge (Eppendorf, Hamburg, Germany). The residues were re-extracted twice where a total volume of 30 ml of the supernatant was kept at – 35 °C for further analysis. The remaining supernatant was evaporated to dryness and later used to determine antimicrobial activity. DIONEX Ultimate 3000 UHPLC system hyphenated with a Thermo high resolution Q Exactive focus mass spectrometer (Thermo Fisher Scientific Australia Pty Ltd., Melbourne, VIC, Australia) was used for analysis as described previously [23, 28].

Quantification of compounds was performed following the method described previously by Bobasa and collaborators [23]. The LCMS system was monitored using Xcalibur™ 4.1 software, while TraceFinder™ 4.1 software was used for data processing. The external calibration curves of gallic acid, ellagic acid, corilagin and 3,4,6-Tri-O-galloyl-β-D-glucose ranging from 0.1 to 50 ppm were used for the equivalent quantification of phenolic compounds [23, 28].

Determination of total phenolic content, DPPH free radical scavenging and vitamin C

Total phenolic content (TPC) was determined using the Folin-Ciocalteu assay described elsewhere [29, 30]. TPC were expressed as gallic acid equivalents per gram DW of sample (mg GAE/100 g DW) [29, 30]. The radical scavenging activity was determined using a DPPH free radical scavenging assay following the method described elsewhere [29, 30]. The results were expressed as Trolox equivalents (TE) per 100 g DW of sample (mM TE /100 g DW). Extraction and determination of vitamin C was conducted using a UHPLC-PDA analysis following the method previously described by Chaliha and collaborators [30].

Antimicrobial activity

To determine the antimicrobial activity of *T. carpentariae* fruit extracts, different foodborne microorganisms were used. The selected microorganisms used in this study were Gram-positive bacteria (*Staphylococcus aureus* NCTC 6571, *Listeria monocytogenes* ATCC 19,111 and methicillin-resistant *Staphylococcus aureus* (MRSA), Gram-negative bacteria (*Escherichia coli* NCTC 9001, *Pseudomonas aeruginosa* ATCC 10,145 and *Pseudomonas aeruginosa* clinical isolates ATCC 9001 and *Shewanella putrefaciens* ATCC 49,138) and fungi (*Aspergillus niger* ATCC 16,888, *Aspergillus flavus* ATCC 20,025 and *Penicillium chrysogenum* ATCC 10,106). The dry extract was freshly reconstituted in 20% (v/v) ethanol to obtain a concentration of 50 mg/ml. A disc diffusion assay was used to evaluate the antimicrobial activity of the fruit extracts as described elsewhere [29]. An aqueous 20% (v/v) ethanol was included to test the effects caused by the solvent as the negative control. 2 mg/ml Oxytetracycline hydrochloride (Sigma-Aldrich, USA) and 1 mg/ml Amphotericin B (Sigma-Aldrich, USA), antibiotic and antifungal substances, were also included as positive controls. The inoculated plates were incubated at 37 °C for 24 h, whilst the inoculated fungal plates were incubated at 25 °C for 48 h. After incubation, the diameter of the inhibition zones was measured using a 150 mm Digital Calliper. The antimicrobial activity results were expressed as strong (> 13 mm), moderate (6–12 mm), weak (≥ 5 mm) and no activity (< 5 mm) [29, 31, 32].

Statistical analysis

The results were expressed as means ± standard deviation (SD) and calculated using GraphPad Prism version 9.0 (San Diego, CA, USA). All the analysis were done in triplicate. Antimicrobial activity was statistically analysed using one-way ANOVA and means compared with Tukey's multiple comparison post hoc tests ($p < 0.05$).

Results and discussion

Morphology, moisture, titratable acidity and total soluble solids

Table 1 reports the morphological parameters measured in the fully mature and wild harvest *T. carpentariae* samples. Published data on fruits from other species such as *T. ferdinandiana* was added for comparison purposes only [21]. The results showed an effect of the species on the morphological characteristics of the fruits (e.g. size). However, the proportion of seed and pulp was relatively similar between the two species (86.6 vs 87%) analysed. Variability in the morphological parameters between individual fruit samples was also observed (weight and size), reflecting the effect of tree variability in the wild. This variability could be also attributed to abiotic effects such as microclimate (e.g. rainfall and temperature), soil, and elevation, as reported by other authors [30, 33, 34]. In this study, fruit samples were collected from two distinctive geographical locations identified as Arnhem Land plateau and lowlands. These regions differ in altitude and this issue might contribute to explain the observed variations in the fruit samples analysed [30, 33, 34]. Table 1 also shows the results for M, pH, TA, and TSS, measured in the *T. carpentariae* fruit samples. Overall, the M, TA and TSS content in the *T. carpentariae* fruit samples analysed is lower than those from *T. ferdinandiana.*

Proximate and mineral composition

Proximate and mineral composition of the *T. carpentariae* fruit samples analysed is reported in Tables 1 and 2, respectively. The CP content (7.2 g/100 g DW) in *T. carpentariae* fruit samples was higher than *T. ferdinandiana* fruits (4.7 g/100 g DW). The TF content of *T. carpentariae* samples was considered low (1.6 g/100 g DW), with most of the fat comprising of PUFA (1.2 g/100 g DW). It was observed that the concentration of PUFA is twice the amount reported for *T. ferdinandiana* (0.6 g/100 g DW), which could be beneficial in reducing the risks of cardiovascular diseases and cancer as reported by other authors [35]. Fruit samples of *T. carpentariae* have a high amount of DF (51.2 g/100 g DW) compared to *T. ferdinandiana*

Table 1 Descriptive statistics for morphology and chemical composition determined in the set of *T. carpentariae* fruit samples

	T. carpentariae	*T. ferdinandiana*[a]
Morphology		
Length (mm)	33.1 ± 3.8 (11.4%)	NA
Width (mm)	19.3 ± 1.9 (9.9%)	NA
Weight (g)	4.5 ± 1.0 (22.9%)	NA
Length range (mm)	21.5–41.2	16.4–37.4
Width range (mm)	11.0–23.6	8.0–20.1
Weight range (g)	2.2–7.3	1.0–4.6
% seed	13.4	13
% pulp	86.6	87
pH	3.7 ± 0.1 (3.1%)	3.8–4.0
TA	1.5 ± 0.2 (1.5%)	3.0–4.8
M (% w/w)	79.2 ± 2.2 (2.8%)	83–87
TSS (°Brix)	11.1 ± 2.2 (20.0%)	19.3–41.1
Vit C[#]	11,046 ± 572 (5.2%)	22,000
L-AA[#]	9,807 ± 344 (3.5%)	NA
DAA[#]	1,239 ± 228	NA
Proximate analysis[$]		
CP	7.2	4.7
TF	1.6	0.9
SFA	0.4	0.3
MFA	0.1	< 0.1
PUFA	1	0.6
TFA	< 0.01	< 0.01
Ash	4.5	5.5
DF	51.2	45.9
CHO	32.9	37

Please note that *T. ferdinandiana* was added for comparative purposes

In brackets coefficient of variation (SD/mean × 100); *TA* titratable acidity, *M* moisture, *TSS* total soluble solids, *CP* crude protein, *L-AA* L-ascorbic acid, *DAA* dehydeoxyascorbic acid, *Vit C* vitamin C, *TF* total fat, *SFA* saturated fatty acids, *MFA* monounsaturated fatty acids, *PUFA* polyunsaturated fatty acids, *TFA* trans fatty acids, *DF* dietary fiber, *CHO* carbohydrates

NA data not available

[a]*T. ferdinandiana* data was sourced from Sultanbawa et al. (2018) and Phan et al. (2020)

[#](mg/100 g DW)

[$](g/100 g DW)

(45.9 g/100 g DW). It was found that the concentration of K, Mg and Zn in the *T. carpentariae* fruit samples analysed was lower than those reported for other species of *Terminalia* [36], while the other minerals analysed in the fruit samples were found at higher concentrations (Table 2). In this study, the concentration of K in the fruit samples was the highest (1780 mg/100 g DW), followed by Ca (373 mg/100 g DW) and Mg (150 mg/100 g DW).

Total phenolic content, DPPH free radical scavenging and vitamin C

The content of vitamin C in the *T. carpentariae* fruit samples analysed was found at a moderate level (11,046 mg/100 g DW) (see Table 1). The concentration of vitamin C in this fruit is comparatively higher than other Australian native fruits such as desert lime (188.6 mg/100 g DW), Davidson's plum (30 mg/100 g DW) and bush tomato (17 mg/100 g DW) [37], however, is lower compared to fruits of *T. ferdinandiana* (22,000 mg/100 g DW [21]. It has been also reported that the concentration of vitamin C (ascorbic acid) varies among the different species of *Terminalia* where a concentration of this vitamin of 797.9 mg/100 g DW and 0.874 mg/100 g DW was reported for *T. chebula* and *catappa*, respectively [38, 39]. This variability may be associated with the accumulation of ascorbic acid in plants, that is influenced by cultivar or species, environment, time of harvest, and post-harvest storage conditions [30].

The TPC in the fruit samples analysed was11,392.9 mg GAE/100 g DW (see Table 3). The content of TPC in these fruits is considered higher than other *Terminalia* species, such as *T. chebula* (40 mg GAE/100 g DW) [40] and *T. catappa* (1005 mg GAE/100 g DW) [41], however, lower than *T. ferdinandiana* fruit (range 37,610 to 50,520 mg GAE/100 g DW) [21] and *T. bellirica* (18,871 GAE mg/100 g DW) [42]. *T. carpentariae* exhibited a high radical scavenging activity with an EC50 value of 12.9 µg/ml. In a recent study, Dharmaratne and collaborators [42] reported higher EC50 values in fruits of *T. bellirica* (6.99 ± 0.15 µg/ml) while Abdulkadir [43] reported weaker free radical scavenging activity in ripe fruits of *T. catappa* (95.99 µg/ml).

Antimicrobial activity

Table 3 reports the antimicrobial activity (shown as inhibition zones) of the *T. carpentariae* fruits extracted (80% methanol) against the foodborne microorganisms selected. Ethanol 20% (negative control) did not show any zone of inhibition against any of the tested microorganisms. The methanolic extracts of *T. carpentariae* showed strong antibacterial activity against the gram-negative *S. putrefaciens*, and moderate activity against *P. aeruginosa* ($p < 0.05$). However, no inhibitory effects against mold, *L. monocytogenes* and *E. coli* were observed. These results suggested that extracts from *T. carpentariae* fruits are more susceptible to bacteria than yeast or fungi, which might be suitable for natural antibacterial applications. Previous studies using other *Terminalia* species have also reported similar trends [29, 44–48]. For example, fruits of *T. chebula* did not exhibit any inhibitory activity against fungi [44]. Extracts of *T. carpentariae* have also showed strong antibacterial activity against gram-positive *S. aureus* and MRSA (Table 3), indicating

Table 2 Content of mineral and trace elements in the set of *T. carpentariae* fruit samples analysed

	T. carpentariae	*T. ferdinandiana*	Nutritional information*
Sodium (Na)	101	40	1300 mg/day AI
Potassium (K)	1780	2717	4.7 g/day AI
Magnesium (Mg)	150	203	350 mg/day EAR
Calcium (Ca)	373	295	1200 mg/day AI
Iron (Fe)	11	1.7	8 mg/day RDA
Zinc (Zn)	1.1	2.15	11 mg/day RDA
Manganese (Mn)	8.8	5.1	2.3 mg/day AI
Cobalt (Co)	0.18	0.01	NA
Cooper (Cu)	3.84	1.4	900 µg/day AI
Nickel (Ni)	0.28	0.49	NA
Chromium (Cr)	0.37	0.07	35 µg/day AI

Please note that *T. ferdinandiana* and nutritional information were added for comparative purposes

T. ferdinandiana data sourced from Sultanbawa et al. (2018)

*Nutritional information was referred to Meyers et al. (2006); (NA) no data available; *AI* adequate intake, *EAR* estimated average requirement, *RDA* recommended dietary allowance. Units; mg/100 g DW

Table 3 (A) Total phenolic content, DPPH free radical capacity, 50% effective concentration (EC50) of DPPH radical scavenging and (B) antimicrobial activity of *T. carpentariae* fruit samples analysed

A		Average ± SD	CV (%)
	TPC (mg GAE/100 g DW)	11,392.9 ± 258.2	2.3
	DPPH (mg TE/g DW)	219.9 ± 1.6	0.7
	EC_{50} (µg/ml DW)	12.9	–
B	Zone of inhibition (mm)	Average ± SD	CV (%)
	S. aureus	20.4 ± 0.8^{a}	4.0
	L. monocytogenes	NI	NI
	MRSA	22.5 ± 0.3^{a}	1.2
	P. aeruginosa	8.2 ± 0.4^{b}	4.4
	P. aeruginosa (CI)	NI	NI
	E. coli	NI	NI
	S. putrefaciens	21.2 ± 0.4^{a}	2.0
	A. niger	NI	NI
	A. flavus	NI	NI
	P. chrysogenum	NI	NI

MRSA methicillin-resistant *Staphylococcus aureus*, Results are means ± SD (n = 3); *CV* coefficient of variation, *NI* no inhibition, different letters (a, b) indicated statistically significant differences at the level ($p \leq 0.05$)

that these fruit extracts have the potential to inhibit bacteria which are resistant to antibiotics. The results of the present study are also in agreement with those reported by other authors using *T. ferdinandiana* [29, 44–48]. Previous reports have also indicated that methanolic extracts of *T. ferdinandiana* were effective as an antibacterial agent against *E. coli* [29, 44, 45]. However, this might be explained by differences in the strain of *E. coli* selected to conduct the present study. Moreover, *P. aeruginosa* and *E. coli* have been considered among the most clinically challenging species to be inhibited or killed by some class of antibiotics [46–48]. Due to the distinctive composition of the outer membrane of gram-negative bacteria, they are more resistant to several antibiotics compared to gram-positive bacteria [46–48]. In our present study, the extracts of *T. carpentariae* showed no zone of inhibition against *E. coli* which might be due to its structure. The strain selected by Cock and Mohanty [45] was more susceptible than the one utilised in the present study. Extracts of *T. carpentariae* were not effective against *L. monocytogenes* while they have shown an inhibitory activity against *P. aeruginosa*. Previous authors have also reported high antimicrobial activity of *T. ferdinandiana* extracts against *L. Monocytogenes* but no inhibition against *P. aeruginosa* [29, 44, 45]. Other authors have also suggested the

synergic effects of vitamin C as antimicrobial agent [4, 29, 44, 45]. Fruit samples of *T. carpentariae* have lower vitamin C than *T. ferdinandiana*, and these might explain the observed differences in antibacterial activity between these two species. In addition, Mohanty and Cock [4] have stated that vitamin C might indirectly improve the antibacterial activity of polyphenolic compounds by inhibiting the oxidation of these compounds. However, results presented in this study are preliminary and require further research to determine the exact mechanism of antimicrobial action of the extracts of *T. carpentariae.*

Phytochemical profiling

Individual phenolic compounds were determined in the *T. carpentariae* fruit samples and reported in both Fig. 1 and supplementary Table. Approximately, a total of 15 phenolic compounds were identified by comparing the mass spectra (MS1 and MS2) with available analytical standards and the scientific literature [49–53]. The compounds identified in Fig. 1 included organic acids (Peak 1), gallotannins (peaks 2, 3, and 4), ellagitannins (peaks 6, 7, 8, 9, and 10), flavone (peaks 14 and 16) and flavone derivatives (peak 11, 12, 13, and 15) [23, 49].

Peak 1 and 2 corresponds with ascorbic acid and gallic acid standards, respectively. Peaks 3, 4 and 7 might be associated with gallotannins [49–53]. Peaks 3 and 4, yield similar molecular ions and could be identified as digalloyl hexoside and its isomer [49–53]. In this study, peak 5 was not identified while peak 6 was identified as corilagin. Peaks 7 and 8, are associated with chebulagic acid as reported by other authors [23, 49–52]. Peak 9 is tentatively identified as avicularin [49–53] while peak 10 was identified as ellagic acid [23, 49–52]. Peak 11 was identified as 5,6-dihydroxy-3′,4′,7-trimethoxy-flavone derivative compounds [23, 49–52]. Peak 14 was identified as tricin [49–53] while peak 16 tentatively identified as 5,6-dihydroxy-3′,4′,7-trimethoxy-flavone [49–53].

It has been reported that ellagitannins exhibited high potential inhibitory effects against bacterial growth and antioxidant properties [13]. Different authors have found that ellagitannins are present in the fruit of different *Terminalia* species, such as *T. bellerica*, *chebula*, *horrida* and *ferdinandiana* [23, 49]. In this study, corilagin was considered the most important phenolic compound found in the fruit of *T. carpentariae*. These results also agreed with those reported by other authors in fruits of *T. bellirica* [19] and *T. ferdinandiana* [23].

Conclusion

This is the first study to investigate the morphology, chemical composition, phytochemical profiling, antioxidant and antimicrobial activity of *T. carpentariae* fruits. Large variability has been observed in both the morphology (e.g.

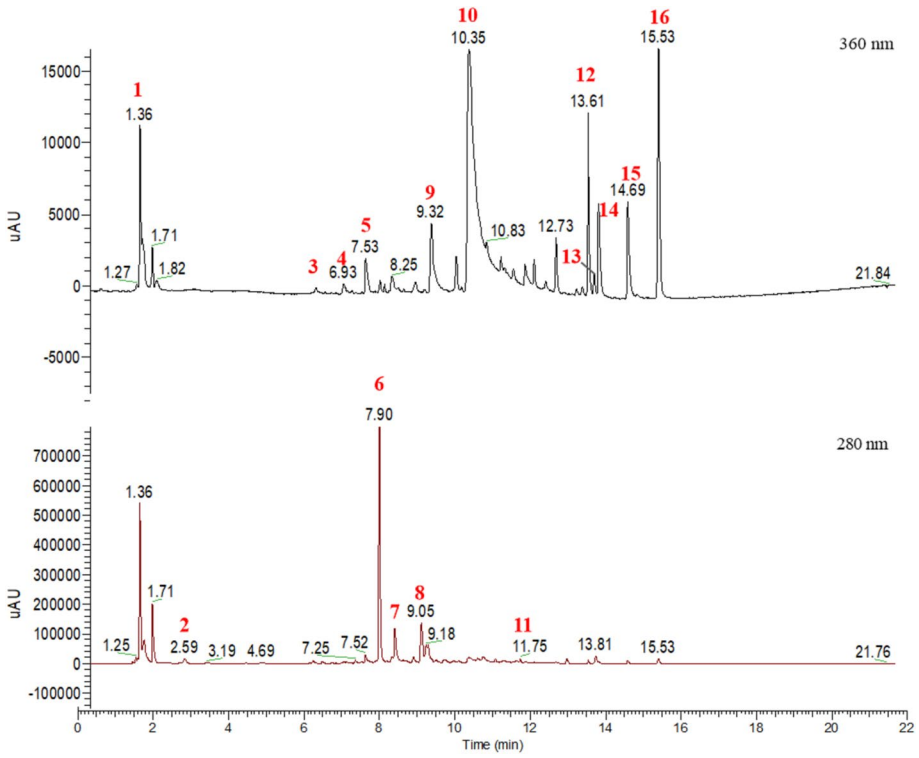

Fig. 1 HPLC–UV chromatogram of *T. carpentariae* fruit samples collected at 280 and 360 nm. The peak number is described in the text and supplementary Table

weight and size) and chemical composition as these fruits were harvested from the wild. Proximate analysis indicated that these fruits are a good source of CP and DF, with high potential as alternative source of minerals such as K, Ca and Mg. The identified phenolic compounds and high levels of vitamin C supported the evidence of the antioxidant and antimicrobial properties of this fruit (high levels of total phenolic content and free radical scavenging capacity). Extracts of *T. carpentariae* exhibited high inhibitory effects against Gram-positive bacteria. These results will contribute to provide with the relevant information of the potential of *T. carpentariae* fruit as a functional ingredient to the Australian Indigenous communities and the emerging Australian native food industry.

Acknowledgements The authors acknowledge the Traditional Owners of the lands on which the *T. carpentariae* fruits were harvested and respect the knowledge and experience the Traditional Owners hold regarding the care, harvest, and use of these plants.

Funding Funding support from the CRC for Developing Northern Australia Limited Project AT.2.1718031—Improving the efficiency of Kakadu plum value chains to grow a robust and sustainable Industry and the Australian Government through the Australian Research Council's (ARC) Industrial Transformation Training Centre (ITTC) for Uniquely Australian Foods (Grant Number: IC180100045) is acknowledged.

Data availability Not applicable.

Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

Code availability Not applicable.

References

1. L.J. McGaw, T. Rabe, S.G. Sparg, A.K. Jager, J.N. Ejoff, J. van Staden, An investigation on the biological activity of Combretum species. J. Ethnopharma. **75**(1), 45–50 (2011)
2. I.E. Cock, The medicinal properties and phytochemistry of plants of the genus Terminalia (Combretaceae). Inflammopharma. **23**(5), 203–229 (2015)
3. A. Intharuksa, H. Ando, K. Miyake, P. Sirisa-Ard, M. Mikage, Y. Sasaki, Molecular analysis of Terminalia spp. distributed in Thailand and authentication of crude drugs from Terminalia plants. Biol. Pharm. Bulletin. **39**(4), 492–501 (2016)
4. S. Mohanty, I.E. Cock, The chemotherapeutic potential of *Terminalia ferdinandiana*: Phytochemistry and bioactivity. Pharmacogn. Rev. **6**(11), 29–36 (2012)
5. M. Netzel, G. Netzel, Q. Tian, S. Schwartz, I. Konczak, Sources of antioxidant activity in Australian native fruits. Identification and quantification of anthocyanins. J. Agric. Food Chem. **54**(26), 9820–9826 (2006)
6. A.S. George, Flora of Australia: Volume 18, Podostemaceae to Combretaceae. Canberra: Australian Government Publishing Service (1990).
7. C. Mazerand, I.E. Cock, The therapeutic properties of plants used traditionally to treat gastrointestinal disorders on *Groote eylandt*, Australia, Evidence-based Com. Alt. Med. Art. 2438491 (2020)
8. M.H. Wright, J. Sirdaarta, A. White, A.C. Greene, I.E. Cock, Bacillus anthracis growth inhibitory properties of Australian Terminalia spp: putative identification of low polarity volatile components by GC-MS headspace analysis. Pharmacognosy J. **83**(1), 281–290 (2016)
9. X.R. Zhang, J.S. Kaunda, H.T. Zhu, D. Wang, C.R. Yang, Y.J. Zhang, The genus Terminalia (combretaceae): an ethnopharmacological, phytochemical and pharmacological review. Nat Prod. Bioprospect. **9**(6), 357–392 (2019)
10. F.E. Kandil, M.I. Nassar, A tannin anti-cancer promotor from *Terminalia arjuna*. Phytochem. **47**(8), 1567–1568 (1988)
11. O.S. Ajala, A. Jukov, C.M. Ma, Hepatitis C virus inhibitory hydrolysable tannins from the fruits of *Terminalia chebula*. Fitoterapia **99**, 117–123 (2014)
12. A. Singh, V. Bajpai, S. Kumar, B. Kumar, M. Srivastava, K.B. Rameshkumar, Comparative profiling of phenolic compounds from different plant parts of six Terminalia species by liquid chromatography–tandem mass spectrometry with chemometric analysis. Ind. Crops Prod. **87**, 236–246 (2016)
13. M. Sobeh, M.F. Mahmoud, R.A. Hasan, M.A. Abdelfattah, S. Osman, H.O. Rashid, M. Wink, Chemical composition, antioxidant and hepatoprotective activities of methanol extracts from leaves of *Terminalia bellirica* and *Terminalia sericea* (Combretaceae). PeerJ **7**, e6322 (2019)
14. R. Rathinamoorthy, G. Thilagavathi, Characterisation and in-vitro evaluation of *Terminalia chebula* extract for antibacterial potential. Int. J. Phar. Pharmac. Sci. **6**(2), 932–938 (2014)
15. S. Debnath, D. Dey, S. Hazra, S. Ghosh, R. Ray, B. Hazra, Antibacterial and antifungal activity of Terminalia arjuna Wight & Arn bark against multi-drug resistant clinical isolates. J. Coastal Life Med. **1**(4), 315–321 (2013)
16. E.K. Kouassi, I. Coulibaly, R. Pop, P. Adela, J.D. Allico, In vitro antioxidant potency and antifungal efficiency of four local Terminalia species against Fusarium strains. J. Exp. Agric. Int. **29**(2), 1–7 (2019)
17. A. Camara, M. Haddad, K. Reybier, M.S. Traoré, M.A. Baldé, J. Royo, A.O. Baldé, P. Batigne, M. Haidara, E.S. Baldé, A. Coste, A.M. Baldé, A. Aubouy, *Terminalia albida* treatment improves survival in experimental cerebral malaria through reactive oxygen species scavenging and anti-inflammatory properties. Malaria J. **18**(1), 431–431 (2019)
18. M.S.A. Khan, N. Khatoon, M.M. Al-Sanea, M.G. Mahmoud, H.U. Rahman, Methanolic extract of leathery murdah, Terminalia coriacea (Roxb.) Wight and Arn. leaves exhibits anti-inflammatory activity in acute and chronic models. Med. Prin. Pract. **27**(1), 267–271 (2018)
19. J. Sirdaarta, B. Matthews, I.E. Cock, Kakadu plum fruit extracts inhibit growth of the bacterial triggers of rheumatoid arthritis: Identification of stilbene and tannin components. J. Fun. Foods. **17**(1), 610–620 (2015)
20. R. Mopuri, M. Ganjayi, K.S. Banavathy, B.N. Parim, B. Meriga, Evaluation of anti-obesity activities of ethanolic extract of *Terminalia paniculata* bark on high fat diet-induced obese rats. BMC Complement. Altern. Med. **15**, 76 (2015)
21. Y. Sultanbawa, M. Chaliha, A. Cusack, D. Edwards, D. Williams, Monitoring quality and bioactivity of Kakadu plum in the Northern Territory. Wagga Wagga, NSW, Australia: AgriFutures Australia (2018)

22. P.D. Johnson, Acerola (Malpighia glabra L., M. punicifolia L., M. emarginata D.C.): agriculture, production and nutrition. World Rev. Nut. Diet. **91**, 67–75 (2003)
23. E.M. Bobasa, A. Dao Thi Phan, M.E. Netzel, D. Cozzolino, Y. Sultanbawa, Hydrolysable tannins in *Terminalia ferdinandiana* Exell fruit powder and comparison of their functional properties from different solvent extracts. Food Chem. **358**(1), 128933 (2021)
24. A. Mandeville, I.E. Cock, *Terminalia chebula* Retz. fruit extracts inhibit bacterial triggers of some autoimmune diseases and potentiate the activity of tetracycline. Indian J. Micro. **58**(4), 496–506 (2018)
25. E.E. Nmema, E.N. Anaele, Susceptibilities of clinical bacteria isolates to two ethanolic extracts of *Terminalia schimperiana*. J. Appl. Sci. Environ. Manage. **17**(4), 595–600 (2013)
26. M. Liu, D.R. Katerere, A.I. Gray, V. Seidel, Phytochemical and antifungal studies on *Terminalia mollis* and *Terminalia brachystemma*. Fitoterapia **80**(6), 369–373 (2009)
27. S.M. Bagher Hashemi, D. Jafarpour, Antimicrobial and antioxidant properties of Saturn peach subjected to ultrasound-assisted osmotic dehydration. J. Food Meas. Charact. **15**, 2516–2523 (2021)
28. A.D.T. Phan, M.S. Damyeh, S., Akter, M. Chaliha, M.E. Netzel, D. Cozzolino, Y. Sultanbawa, Effects of fruit maturity on physicochemical properties, sugar accumulation and antioxidant capacity of wild harvested Kakadu plum (*Terminalia ferdinandiana*), Proceedings. **70**(1) (2020).
29. S. Akter, M.E. Netzel, U. Tinggi, S.A. Osborne, M.T. Fletcher, Y. Sultanbawa, Antioxidant rich extracts of *Terminalia ferdinandiana* inhibit the growth of foodborne bacteria, Foods, **8**(8), (2019)
30. M. Chaliha, A.D.T. Phan, S. Cao, Q. Li, J. Gorman, Y. Sultanbawa, D. Cozzolino, Antimicrobial activity, total phenolic and ascorbic acid content of *Terminalia ferdinandiana* leaves at various stages of maturity. Curr. Res. Nut. Food Sci. J. **8**(3), 744–756 (2020)
31. H. Mosbah, H. Louati, M.A. Boujbiha, H. Chahdoura, M. Snoussi, B. Flamini, B. Selmi, Phytochemical characterization, antioxidant, antimicrobial and pharmacological activities of *Feijoa sellowiana* leaves growing in Tunisia. Ind. Crop. Prod. **112**, 521–531 (2018)
32. S.M. Bagher Hashemi, D. Jafarpour, Synergistic properties of *Eucalyptus caesia* and *Dracocephalum multicaule* Montbr & Auch essential oils: Antimicrobial activity against food borne pathogens and antioxidant activity in pear slices. J. Food Process Preserv. **44**, e14651 (2020)
33. L.J. McKenzie, Proceedings of a workshop for mapping and monitoring seagrass habitats in Northeast Arnhem Land, Northern Territory (S.-W. HQ Ed.). Cairns, Australia (2008)
34. M. Marjenah, N.P. Putri, Morphological characteristic and physical environment of *Terminalia catappa* in East Kalimantan, Indonesia. Asian J. For. **1**(1), 33–39 (2017)
35. O.A. Idris, O.A. Wintola, A.J. Afolayan, Comparison of the proximate composition, vitamins (ascorbic acid, alpha-tocopherol and retinol), anti-nutrients (phytate and oxalate) and the GC-MS analysis of the essential oil of the root and leaf of *Rumex crispus* L, Plants (Basel), **8**(3) (2019)
36. P.C. Anuforo, K.A. Ngozi, A.C.C. Egbuonu, E.U. Egu, Proximate analysis and determination of some selected vitamins and minerals contents of *Terminalia catappa* endocarp flour. J. Nut. Health Food Sci. **5**(5), 1–4 (2017)
37. R. Richmond, M. Bowyer, Q. Vuong, Australian native fruits: potential uses as functional food ingredients. J. Func. Foods **62**, 1–16 (2019)
38. J.I.R. Udotong, M.I. Bassey, Evaluation of the chemical composition, nutritive value and antinutrients of *Terminalia catappa* L. fruit (Tropical Almond). Int. J. Eng. Tech. Res. **3**(9), 96–99 (2015)
39. S. Saha, R.J. Verma, Antioxidant activity of polyphenolic extract of *Terminalia chebula* Retzius fruits. J. Taibah Univ. Sci. **10**(6), 805–812 (2018)
40. K. Balaji, L.H. Ni, B. Rajindran, M.S. Sikarwar, N.K. Fuloria, S. Fuloria Determination of total phenolic, flavonoid content and antioxidant activity of *Terminalia chebula* (Fruit). Res. J. Pharma., Biol. Chem. Sci. **6**(2), 413–317 (2015)
41. S. Ishtiaque, S. Naz, R. Siddiqi, S.U. Abdullah, K. Khan, J. Ahmed, M. Badaruddin, Antioxidant activities and total phenolics contents from extracts of *Terminalia catappa*, *Carrisa carandas*, and *Opuntia ficus indica* fruits. Rec. Innov. Chem. Eng. **7**(2), 106–112 (2014)
42. M.P.J. Dharmaratne, A. Manoraj, V. Thevanesam, A. Ekanayake, N.S. Kumar, V. Liyanapathirana, B.M.R. Bandara, *Terminalia bellirica* fruit extracts: in-vitro antibacterial activity against selected multidrug-resistant bacteria, radical scavenging activity and cytotoxicity study on BHK-21 cells. BMC Comp. Altern. Med. **18**(1), 325 (2018)
43. R.B. Abdulkadir, In vitro antioxidant activity of ethanolic extract from *Terminalia catappa* (L.) leaves and fruits: effect of fruit ripening. Int. J. Sci. Res. **4**(8), 1244–1248 (2015)
44. M. Mahdia, R. Mahdia, M.M. Karim, Antimicrobial activity of I. Int. J. Med. Arom **1**(2), 175–179 (2011)
45. I.E. Cock, S. Mohanty, Evaluation of the antibacterial activity and toxicity of *Terminalia ferdinandiana* fruit extracts. Pharm. J. **3**(20), 72–79 (2011)
46. A.F. Burlec, L. Pecio, S. Kozachok, C. Mircea, A. Corciovă, L. Vereştiuc, O. Cioancă, W. Oleszek, M. Hăncianu, Phytochemical profile, antioxidant activity, and cytotoxicity assessment of *Tagetes erecta* L. flowers. Molecules (Basel, Switzerland) **26**(5), 1201 (2021)
47. B. Zeinab, B. Jubeh, R. Karaman, Resistance of Gram-negative bacteria to current antibacterial agents and approaches to resolve it. Molecules **25** (2020)
48. S.M.B. Hashemi, D. Jafarpour, M. Jouki, Improving bioactive properties of peach juice using Lactobacillus strains fermentation: antagonistic and anti-adhesion effects, anti-inflammatory and antioxidant properties, and Maillard reaction inhibition. Food Chem. **365**, 130501 (2021)
49. O. López-Fernández, R. Domínguez, M. Pateiro, P. Munekata, G. Rocchetti, J.M. Lorenzo, Determination of polyphenols using liquid chromatography-tandem mass spectrometry technique (LC-MS/MS): a review. Antioxidants (Basel, Switzerland) **9**(6), 479 (2020)
50. Z. Chang, Q. Zhang, W. Liang, K. Zhou, P. Jian, G. She, L. Zhang, A comprehensive review of the structure elucidation of tannins from *Terminalia linn*. Evidence-Based Comp. Alt. Med. **2019**, 1–26 (2019)
51. L. Zhong, Z. Yuan, L. Rong, Y. Zhang, G. Xiong, Y. Liu, C. Li, An optimized method for extraction and characterization of phenolic compounds in Dendranthema indicum var. aromaticum flower. Sci. Rep. **9**, 7745 (2019)
52. E. Salih, P. Fyhrquist, A. Abdalla, A.Y. Abdelgadir, M. Kanninen, M. Sipi, O. Luukkanen, M. Fahmi, M.H. Elamin, H.A. Ali, LC-MS/MS tandem mass spectrometry for analysis of phenolic compounds and pentacyclic triterpenes in antifungal extracts of *Terminalia brownii* (Fresen). Antibiotics (Basel, Switzerland) **6**(4), 37–40 (2017)
53. L.D. Meyers, J.P. Hellwig, J.J. Otten, Dietary reference intakes: the essential guide to nutrient requirements. National Academies Press (2006)