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## Nutritional composition of New Zealand native shrubs edible portions with fodder potential for ruminants

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### ABSTRACT

In New Zealand, willow and poplar are used on hill farms for erosion control and to supplement pasture during low pasture periods. Some native shrubs are browsed by wild herbivores but remain unexplored for farmed ruminants. We evaluated the seasonal nutritional composition of five native New Zealand shrubs (Karamū, Pāpāuma, Karo, Whauwhaupaku, and Houhere) and compared them with willow (Kinuyanagi). Leaf and edible stem were analysed for nutritional composition and *in vitro* digestibility following AOAC procedures. Results showed that except Houhere, all other native shrubs leaves had lower crude protein (CP) (11 MJ/ kg DM) than Kinuyanagi. Kinuyanagi leaves were comparable to Houhere in ME and CP in spring but had lower CP in summer. Stem nutritional composition was similar across all shrubs. Acid and neutral detergent fibres in edible portions were comparable to those in common pastures, fodder crops, and forages in New Zealand. The findings suggest native shrubs could supplement low ME in summer pastures or winter herbage scarcity, but further research is needed on animal preference and intake.

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Native shrubs; nutritional composition; *Salix schwerinii*; Karamū; Pāpāuma; Karo; Whauwhaupaku; Houhere

## Introduction

Forage shrubs are an important feed resource that can be used to lessen feed deficits in areas that experience seasonal pasture quantity and quality fluctuations (Eichhorn et al. 2006). In arid and semi-arid pastoral grazing systems, shrub browse is a major feed supply, particularly during the dry seasons when herbaceous pastures senesce (Akbag 2021). Forage shrubs integrated in agroforestry often provide non-conventional supplementary feed in mixed crop and livestock farming systems (Vandermeulen et al. 2018). However, in temperate regions, such as New Zealand, where climatic conditions can generally support year-round growth of pastures, the use of forage shrubs as feed resources is commonly of a secondary role (Vandermeulen et al. 2018). As a result,

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shrubs and trees have progressively been cleared for pasture expansion (Eichhorn et al. 2006), leading to negative impacts on the environment (Wedderburn et al. 2020). However, the role of forage shrubs and trees in providing ecosystem services with an additional role as a supplementary feed resource in the pastoral farming landscapes in New Zealand is gradually being acknowledged (Dickinson et al. 2015).

New Zealand pastoral farming is dominated by sheep and beef cattle that rely on pastures for more than 95% of their dietary requirements (Pain et al. 2015). More than half of these pastoral farms are classified as hill country and are characterised by flat (11%), rolling (32%) and steep slopes (40%) (Beef+Lamb NZ 2020). Hill country topography influences pasture composition, distribution and production (Radcliffe 1982). The flat and rolling areas contain improved pastures mainly a mix of perennial ryegrass and white clover pasture (Beef+Lamb NZ 2020), while the steep slopes are mostly unimproved and have high proportions of Browntop, Yorkshire fog and sweet vernal pastures (Waghorn and Clark 2004). However, the quality and quantity of the pastures deteriorate during the summer and autumn seasons, which coincides with increased feed demand for lambs and calves weaning and ewe flushing and steaming up, respectively (Beef+Lamb NZ 2018). The deterioration of pasture quality is greatest on the steep slopes of hill country farms (Kemp and Lopez 2016).

There is limited ability to plant and utilise improved pastures on steep slopes because of the thin soil, poor fertility, low moisture, and high vulnerability to soil mass movement (Kemp and Lopez 2016). A common option on the steep slopes is the use of exotic willows and poplar that are primarily planted for erosion control and windbreaks, but also supply supplemental fodder when coppiced or browsed (Benavides et al. 2009). However, willows and poplar are deciduous which limit their supplemental feed supply only during the spring and summer seasons (Benavides et al. 2009). Exotic forest species such as radiata pine may also be planted for timber production but offer no nutritive value to ruminants and expose the steep slopes to cyclic soil mass movement during harvesting (Benavides et al. 2009; Cairns et al. 2001). A further recent option is to integrate native shrubs on steep slopes because they can offer the ecosystem services provided by the exotic species and provide fodder or browse (Dickinson et al. 2015).

Native shrubs account for approximately 16% of New Zealand's indigenous flora and comprise more than 400 taxa of which, approximately 80% are endemic to New Zealand (Kerr and Stewart 2014). Most native shrubs are evergreen and can be used as a refuge for vulnerable livestock during cold or wet weather. Native shrubs with forage potential can supply supplemental fodder or browse when pasture growth and quality are low, especially during summer and winter. Additionally, native shrubs can provide several benefits for hill country farm landscapes including erosion control, increased indigenous biodiversity, and carbon sequestration (Pannell et al. 2021). Some New Zealand native shrubs are palatable and highly preferred by deer and wild herbivores (Bee et al. 2011). However, the nutritive value of the browse native shrubs to farmed ruminant has not been fully explore (Dickinson et al. 2015; Wangui et al. 2022). Browse quantity that can be obtained from the native shrubs is also unknown (Wangui et al. 2021).

Profiling the nutritional composition of some potential forage native shrubs is of benefit to hill country sheep and beef farmers, policymakers, and researchers, as it will likely impact the selection of shrubs for hill country landscape management and

improvement. Therefore, the purpose of this study was to evaluate the nutritional composition of five browsable New Zealand native shrubs with the potential to provide forage for ruminants. Specifically, the study objectives were to determine the proximate nutritional composition of leaf and stem (less than 5 mm in diameter) of Karamū, Pāpāuma, Houhere, Karo and Whauwhaupaku and an exotic osier willow (Kinuyanagi) and to compare them across and within the seasons.

## Materials and methods

### *Description of shrub species used in the study*

The term shrub in this study was used to refer to woody plants with a bushy growth habit, that differ from trees chiefly in height (David and Mikaila 2008). All the native shrubs used in the study are endemic to New Zealand but vary in taxonomy and physiognomy. *Coprosma robusta* (Karamū) is among the widely distributed native shrubs in New Zealand due to its fast growth and nature of colonising newly open areas (de Lange 2022a). It belongs to the Rubiaceae family and is characterised by numerous branches, glabrous elliptical leaves, and an erect or spreading growth of up to 6 m (Metcalf 2011). *Griselinia littoralis* (Pāpāuma) is a heavily branched erect shrub growing up to 15 m and belongs to the Griselinaceae family (Metcalf 2011). The shrub has glossy rounded leaves that are paler underneath and attached to yellow-pigmented branchlets (Metcalf 2011). *Hoheria populnea* (Houhere) belongs to the Malvaceae family (Metcalf 2011), has an erect or spreading growth of up to 9 m and serrated ovate leaves and maroon-tinted petioles and leaf veins (de Lange 2022b). *Pittosporum crassifolium* (Karo) belongs to the Pittosporaceae family and grows up to 9 m as an erect heavily branched shrub with characteristic woolly tomentum on branchlets and underside of leaves (de Lange 2022c). *Pseudopanax arboreus* (Five Finger) is a multi-branched shrub growing up to 8 m belonging to Araliaceae family (de Lange 2022d). However, unlike the other native shrubs, *P. arboreus* has palmate leaves with five leaflets, is dioecious, and is frequently epiphytic (Metcalf 2011). *Salix schwerinii* (Kinuyanagi) is a deciduous osier willow in the Salicaceae family that is exotic to New Zealand (McIvor et al. 2006). It is characterised by spreading multi-stemmed growth of up to 6 m and has dense silvery pubescence on branchlets and linear leaves (McIvor et al. 2006).

### *Study sites description*

The shrub samples used in this study were collected from a trial site on Massey University Dairy4 farm in Palmerston North. Massey University Dairy4 farm is located five kilometres south of Palmerston North city. The long-term climatic conditions for Palmerston North district (Chappell 2015) are defined in Table 1. The trial site on Dairy4 farm was located (Lat  $-40.401447$ , Long  $175.617912$ ) on a steep slope ( $>25^\circ$ ) with a southerly aspect. Dominant soil types at the trial site were Tokomaru silt loam soil at the top and Ohakea silt at the bottom of the slope and were characterised by average natural fertility and fair to poor drainage (Cowie and Rijkse 1977). The trial site was set up in a randomised complete block design (RCBD) of four blocks in a two-by-two block arrangement and each block had eight plots. Eight trial shrub species consisting

**Table 1.** Summarised long-term seasonal climatic conditions for the Palmerston north district (Chappell 2015).

Climate parameters		Season			
		Summer	Autumn	Winter	Spring
Temperature	Mean (°C)	17.4	13.8	9.0	12.4
	Total (mm)	222.0	189.0	246.0	43.7
Rainfall	Percent of total rainfall (%)	25.0	21.0	27.0	26.0
	Average monthly rain days (d)	11.7	12.7	17.7	15.3

of five native shrubs (*C. robusta*, *G. littoralis*, *H. populnea*, *P. crassifolium* and *P. arboreus*), two native species Hawkes Bay ecotypes (*G. littoralis* and *P. arboreus*) and osier willow (*S. schwerinii*) were randomly allocated to the plots in each of the blocks, such that all the four blocks had all eight shrubs. Each of the plots had a total of 15 shrubs, planted in three rows and five columns, and spaced at 1.5 m by 1.5 m apart. The site was used for dairy cattle grazing prior to planting the shrubs.

### Sample collection

Seedlings for the native species and poles for *S. schwerinii* were planted on the Massey University Dairy4 trial site during the winter season in August 2019. Foliage samples from the trial site were collected during the summer and spring of 2020 and the winter of 2021 corresponding to approximately 390, 430, and 760 days after planting, respectively. The foliage samples were leaved stems with a diameter of less than 5 mm. Foliage with a diameter of less than 5 mm contains mostly new growth and soft stems that sheep can consume (Karachi 1998; Kemp et al. 2001). Five shrubs for each of the species in each plot were randomly selected and at least five foliage samples were harvested from each shrub. The foliage samples were indiscriminately harvested from the lower, middle, and top parts (not higher than 1.1 m) of the shrub to imitate the browsing behaviour of the sheep (Sanon et al. 2007) and to ensure the samples were representative of the entire shrub to the height of sheep browsing. Harvested foliage samples were then pooled for each shrub species in each plot. A total of four pooled samples were collected for each species in each season. All the shrubs were sampled from the trial site except the Hawkes Bay ecotypes for all seasons and *S. schwerinii* in winter due deciduousness. Therefore, 24 foliage samples were collected during the spring and summer seasons and 20 foliage samples in the winter season.

### Sample processing

Collected foliage samples were labelled, and chilled to approximately 4°C while being processed. Any foreign materials such as grass, dead leaves, and non-plant matter were removed before separating the foliage samples into leaf and stem sub-samples. The leaf sub-sample consisted of the leaf blade, stipules, buds, and petiole, while the stem sub-sample included the woody and soft bark where the leaves were attached. The sub-samples were frozen before submission to the Massey University Food and Nutrition Laboratory for freeze drying (CUDDON, model FD18LT, New Zealand), grinding, and proximate nutritional composition analysis.

### **Proximate nutritional analysis and *in vitro* digestibility**

The leaf and stem sub-sample dry matter content (DM) was determined as percentage of the weight remaining after moisture loss during freeze drying and was estimated using the AOAC (Association of Official Agricultural Chemists) 925.10, 930.15 calculation. Pyrolysis and combustion following AOAC 968.06 (Dumas) method was used to estimate total nitrogen, which was multiplied by 6.25 to estimate the crude protein (CP) content in the sub-samples (Waghorn et al. 2017). Ash content was determined by combusting the organic matter (OM) portion of the DM in a Furnace at 550°C following the AOAC 942.05 (Feed, meat) method. Fibre fractions were estimated following AOAC 2002.04 method for neutral detergent fibre (NDF) and AOAC 973.18 for acid detergent fibre (ADF) and acid detergent lignin (ADL) using the Fibretec system.

*In vitro* dry matter digestibility (IVDMD) and organic matter digestibility (IVOMD) were estimated by treating samples with a neutral detergent solution and digesting with pepsin and fungal cellulase enzymes as described by (Roughan and Holland 1977). Digestible organic content in the dry matter (IVDOMD) was calculated as a product of sub-sample OM (100- ash) and IVOMD and expressed as a percentage of the DM. The IVDOMD was used to derive the metabolisable energy (ME, MJ/kg DM) by multiplying with a factor of 0.16 (Agricultural and Food Research Council (Great Britain) 1993).

### **Statistical analysis**

The MIXED procedure of SAS software (Version 9.4, SAS Institute Inc. Cary, NC, USA) was used in the data analysis. Data was organised in a randomised complete block design statistical model (Equation (1)) with sampled shrubs as replicates. (spring, summer, and winter) The model was run separately for the leaf and stem because the leaf and edible stem of woody plants are morphologically distinct plant parts and vary in structural and nutritional composition.

$$y_{ijk} = S_{T_i} + W_j + (S_{T_i}:W)_{ij} + B_k + e_{ijk} \quad (1)$$

where

$y_{ijk}$ : represents the determined shrub nutritional composition.

$S_{T_i}$ : Fixed effect of shrub sub-sample (leaf or stem).

$W_j$ : Season (spring, summer, and winter).

$(S_{T_i}:W)_{ij}$ : Two-way interaction between shrub sub-sample and season

$B_k$ : Random effect of the block

$e_{ijk}$ : Random error term (unexplained variability in the nutritional composition that cannot be accounted for by the other factors in the model).

The main effects, their two-way interaction, and the block effect on the nutritional composition were determined using the least squares means method at  $\alpha = 0.05$  and the different means were separated using the Tukey post hoc test. Since *S. schwerinii* is deciduous and no foliage was collected in the winter season, only the spring and summer seasons data were used for the species in the statistical analysis.

## Results

### Main effects on nutritional composition

Table 2 shows a summary of the main effects on shrub nutritional composition. Shrub sub-sample (leaf or stem) and season showed a significant ( $p < 0.05$ ) two-way interaction on the chemical composition. In addition, block effect was not significant ( $p > 0.05$ ) in reducing the variability of nutritional composition for the leaf and stem, except for the leaf ME and stem ash content.

### Leaf nutritional composition across seasons

The changes in season greatly affected the leaf dry matter content (DM), acid detergent fibre (ADF), neutral detergent fibre (NDF), and metabolisable energy (ME) for most shrubs (Table 3). *Hoheria populnea* showed greater variability in nutritional composition (all except lignin), while *P. arboreus* had the least variability (only DM) across seasons. All native shrubs DM was higher ( $p < 0.05$ ) in winter and lower ( $p < 0.05$ ) in summer except for *C. robusta* which showed no difference ( $p > 0.05$ ) across the seasons. *Salix schwerinii* DM did not differ ( $p > 0.05$ ) between spring and summer. Ash content for all shrubs did not differ ( $p > 0.05$ ) across the seasons except for *H. populnea* and *P. crassifolium* which had lower ( $p < 0.05$ ) ash in the spring season. All the native shrubs crude protein (CP) did not differ ( $p > 0.05$ ) across seasons, except for *H. populnea* which had lower ( $p < 0.05$ ) CP in summer than in winter and spring seasons, which did not differ ( $p > 0.05$ ). The CP for *S. schwerinii* was higher ( $p < 0.05$ ) in spring than in summer. Native shrubs had higher ( $p < 0.05$ ) ADF in winter than in the other seasons, while the NDF showed an inverse trend. However, the ADF for *G. littoralis* and *P. arboreus* did not differ ( $p > 0.05$ ) across the seasons. In contrast, the fibre contents (ADF and NDF) were higher ( $p < 0.05$ ) in summer and lower in spring for *S. schwerinii*. The lignin content did not differ ( $p > 0.05$ ) across seasons for all the native shrubs but was higher ( $p < 0.05$ ) in summer than in winter for *S. schwerinii*. The ME was lower ( $p < 0.05$ ) in summer for all shrubs, except for *G. littoralis* and *P. arboreus* that had no difference ( $p > 0.05$ ) across the seasons.

**Table 2.** Statistical significance of shrub (leaf vs stem), seasons and their interactions and block on nutritional composition: DM (% wet weight), ash, CP, ADF, NDF, lignin, ME (MJ/kg DM), IVDMD, IVOMD and IVDOMD, all expressed as % DM except where indicated.

Nutrients	Leaf	Season	Leaf×Season	Block	Stem	Season	Stem×Season	Block
DM (% wet weight)	<0.001	<0.001	<0.001	0.150	<0.001	<0.001	0.017	0.079
Ash (% DM)	<0.001	0.003	<0.001	0.203	<0.001	0.069	<0.001	<0.001
CP (% DM)	<0.001	<0.001	<0.001	0.442	<0.001	0.005	<0.001	0.357
ADF (% DM)	<0.001	0.010	0.007	0.322	<0.001	0.434	0.063	0.450
NDF (% DM)	<0.001	0.740	<0.001	0.058	<0.001	0.303	0.004	0.497
Lignin (% DM)	<0.001	0.007	0.042	0.709	<0.001	0.067	0.037	0.882
ME (MJ/ kg DM)	<0.001	<0.001	<0.001	0.039	<0.001	0.689	<0.001	0.396
IVDMD (% DM)	<0.001	<0.001	<0.001	0.092	<0.001	0.080	<0.001	0.326
IVOMD (% DM)	<0.001	<0.001	<0.001	0.068	<0.001	0.427	<0.001	0.421
IVDOMD (% DM)	<0.001	<0.001	<0.001	0.041	<0.001	0.685	<0.001	0.452

Dry matter (DM), crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), metabolisable energy (ME), *in vitro* dry matter digestibility (IVDMD), organic matter digestibility (IVOMD) and digestible organic matter digestibility (IVDOMD).

**Table 3.** Effect of seasons on leaf nutritional composition: DM (% wet weight), ash, CP, ADF, NDF, lignin and ME (MJ/kg DM), for the native (*C. robusta*, *G. littoralis*, *H. populnea*, *P. crassifolium* and *P. arboreus*) and exotic (*S. schwerinii*) shrub species.

Species	Season	DM	Ash	CP	ADF	NDF	Lignin	ME
<i>Coprosma robusta</i>	Spring	39.3	7.0	7.9	22.4 <sup>b</sup>	37.4 <sup>a</sup>	9.6	12.0 <sup>ab</sup>
	Summer	35.5	7.3	7.7	24.5 <sup>b</sup>	34.6 <sup>a</sup>	12.0	11.5 <sup>b</sup>
	Winter	38.0	7.0	9.5	34.1 <sup>a</sup>	24.5 <sup>b</sup>	13.1	12.2 <sup>a</sup>
	SE	1.07	1.16	0.29	0.69	1.66	1.63	0.07
<i>Griselinia littoralis</i>	Spring	31.5 <sup>ab</sup>	7.3	6.2	22.3	32.1 <sup>a</sup>	12.0	11.9
	Summer	31.0 <sup>b</sup>	7.2	6.2	22.3	31.0 <sup>a</sup>	13.0	11.7
	Winter	36.3 <sup>a</sup>	6.9	7.2	30.6	20.8 <sup>b</sup>	12.5	12.2
	SE	1.10	0.22	0.29	0.94	0.96	1.19	0.06
<i>Hoheria populnea</i>	Spring	31.1 <sup>b</sup>	11.6 <sup>b</sup>	14.0 <sup>a</sup>	20.2 <sup>b</sup>	37.6 <sup>a</sup>	7.5	11.4 <sup>a</sup>
	Summer	28.2 <sup>b</sup>	11.7 <sup>b</sup>	11.2 <sup>b</sup>	24.9 <sup>b</sup>	39.1 <sup>a</sup>	7.3	10.4 <sup>b</sup>
	Winter	41.2 <sup>a</sup>	13.1 <sup>a</sup>	13.4 <sup>a</sup>	36.5 <sup>a</sup>	20.4 <sup>b</sup>	6.6	10.6 <sup>b</sup>
	SE	2.61	0.59	1.08	4.87	3.67	1.43	0.35
<i>Pittosporum crassifolium</i>	Spring	43.0 <sup>a</sup>	6.5 <sup>b</sup>	6.2	20.7 <sup>b</sup>	36.4 <sup>a</sup>	9.3	12.0 <sup>a</sup>
	Summer	37.8 <sup>b</sup>	8.3 <sup>a</sup>	7.3	20.0 <sup>b</sup>	30.2 <sup>ab</sup>	9.1	11.2 <sup>b</sup>
	Winter	46.8 <sup>a</sup>	7.3 <sup>ab</sup>	7.5	38.1 <sup>a</sup>	24.8 <sup>b</sup>	10.1	11.6 <sup>ab</sup>
	SE	1.02	0.24	0.28	3.00	2.14	0.46	0.13
<i>Pseudopanax arboreus</i>	Spring	39.5 <sup>ab</sup>	6.7	5.2	15.6	22.4	8.3	12.3
	Summer	36.0 <sup>b</sup>	6.2	5.4	15.4	21.6	9.2	12.2
	Winter	41.3 <sup>a</sup>	7.1	5.6	21.7	16.8	8.7	12.3
	SE	0.99	0.26	0.26	0.66	1.76	0.50	0.07
<i>Salix schwerinii</i>	Spring	43.1	4.9	15.1 <sup>a</sup>	24.6 <sup>b</sup>	36.3 <sup>b</sup>	8.8 <sup>b</sup>	11.3 <sup>a</sup>
	Summer	42.3	5.5	8.3 <sup>b</sup>	35.0 <sup>a</sup>	50.0 <sup>a</sup>	13.3 <sup>a</sup>	10.5 <sup>b</sup>
	SE	0.88	1.88	0.85	0.86	1.56	0.48	0.07

Notes: All the nutrients are expressed as % DM except where indicated.

Nutrient values for each shrub with different letter superscripts across the seasons are different at  $p < 0.05$ . Summer samples ( $n = 24$ ), spring ( $n = 24$ ) and winter ( $n = 20$ ). SE is Standard error. Dry matter (DM), crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF) and metabolisable energy (ME).

### Comparison of leaf nutritional composition among shrubs within seasons

Leaf nutritional composition differed among the native shrubs and with *S. schwerinii* within seasons (Table 4). *Pittosporum crassifolium* had generally higher DM than all the other native shrubs and did not differ from *S. schwerinii* in the spring and summer seasons. *Hoheria populnea* ash content was higher ( $p < 0.05$ ) in all seasons than all the other native shrubs, which did not differ ( $p > 0.05$ ) in the spring and winter seasons. Compared to the native shrubs, *S. schwerinii* ash content was lower ( $p < 0.05$ ) in both spring and summer. The CP was higher for *H. populnea* than for all the other native shrubs in all the seasons. However, the CP for *S. schwerinii* was comparable ( $p > 0.05$ ) to that of *H. populnea* in the spring season and to that of other native shrubs in summer. The fibre contents were lower ( $p < 0.05$ ) for *P. arboreus* than all the other native shrubs which were similar ( $p > 0.05$ ) in the spring and winter seasons. *Salix schwerinii* fibre contents were higher ( $p < 0.05$ ) than for native shrubs in summer but similar ( $p > 0.05$ ) to all the native shrubs except *P. arboreus* in spring. The lignin content was higher ( $p < 0.05$ ) for *G. littoralis* and lower ( $p < 0.05$ ) for *H. populnea* among native shrubs in all seasons. *Salix schwerinii* leaf lignin content was similar ( $p > 0.05$ ) to that for native shrubs except for *H. populnea* in spring and comparable ( $p > 0.05$ ) to that for *G. littoralis* and *C. robusta* in summer. The ME was lower ( $p < 0.05$ ) for *H. populnea* than for all the other native shrubs in summer and winter and similar ( $p > 0.05$ ) to that for *S. schwerinii* in both spring and summer.

**Table 4.** Comparison of leaf nutritional composition: DM (% wet weight), ash, CP, ADF, NDF, lignin and ME (MJ/kg DM) for the native (*C. robusta*, *G. littoralis*, *H. populnea*, *P. crassifolium* and *P. arboreus*) and exotic (*S. schwerinii*) shrub species within seasons (spring, summer, winter).

Shrub	DM	Ash	CP	ADF	NDF	Lignin	ME
<b>Spring</b>							
<i>Coprosma robusta</i>	39.3 <sup>ab</sup>	7.0 <sup>b</sup>	8.0 <sup>b</sup>	22.4 <sup>ab</sup>	37.5 <sup>a</sup>	9.6 <sup>ab</sup>	12.0 <sup>a</sup>
<i>Griselinia littoralis</i>	31.6 <sup>c</sup>	7.3 <sup>b</sup>	6.2 <sup>bc</sup>	22.3 <sup>ab</sup>	32.1 <sup>a</sup>	12.0 <sup>a</sup>	11.9 <sup>ab</sup>
<i>Hoheria populnea</i>	31.1 <sup>c</sup>	11.6 <sup>a</sup>	14.0 <sup>a</sup>	20.2 <sup>ab</sup>	37.6 <sup>a</sup>	7.5 <sup>b</sup>	11.4 <sup>bc</sup>
<i>Pittosporum crassifolium</i>	43.0 <sup>ab</sup>	6.5 <sup>b</sup>	6.2 <sup>bc</sup>	20.7 <sup>ab</sup>	36.4 <sup>a</sup>	9.3 <sup>ab</sup>	11.9 <sup>ab</sup>
<i>Pseudopanax arboreus</i>	39.5 <sup>ab</sup>	6.7 <sup>b</sup>	5.3 <sup>c</sup>	15.6 <sup>b</sup>	22.4 <sup>b</sup>	8.3 <sup>ab</sup>	12.4 <sup>a</sup>
<i>Salix schwerinii</i>	43.1 <sup>a</sup>	4.9 <sup>c</sup>	15.1 <sup>a</sup>	24.6 <sup>a</sup>	36.3 <sup>a</sup>	8.9 <sup>ab</sup>	11.3 <sup>c</sup>
<b>Summer</b>							
<i>Coprosma robusta</i>	35.6 <sup>cb</sup>	7.3 <sup>bc</sup>	7.7 <sup>b</sup>	24.5 <sup>b</sup>	34.6 <sup>bc</sup>	12.0 <sup>ab</sup>	11.5 <sup>bc</sup>
<i>Griselinia littoralis</i>	31.0 <sup>cd</sup>	7.2 <sup>bc</sup>	6.2 <sup>bc</sup>	22.3 <sup>bc</sup>	31.0 <sup>c</sup>	13.0 <sup>ab</sup>	11.7 <sup>abc</sup>
<i>Hoheria populnea</i>	28.2 <sup>d</sup>	11.7 <sup>a</sup>	11.2 <sup>a</sup>	24.9 <sup>b</sup>	39.1 <sup>b</sup>	7.3 <sup>c</sup>	10.4 <sup>d</sup>
<i>Pittosporum crassifolium</i>	37.8 <sup>ab</sup>	8.3 <sup>b</sup>	7.3 <sup>bc</sup>	20.0 <sup>bc</sup>	30.3 <sup>c</sup>	9.1 <sup>bc</sup>	11.2 <sup>c</sup>
<i>Pseudopanax arboreus</i>	36.0 <sup>bc</sup>	6.2 <sup>cd</sup>	5.4 <sup>c</sup>	15.4 <sup>c</sup>	21.6 <sup>d</sup>	9.2 <sup>bc</sup>	12.2 <sup>ab</sup>
<i>Salix schwerinii</i>	42.4 <sup>a</sup>	5.5 <sup>d</sup>	8.3 <sup>b</sup>	35.0 <sup>a</sup>	50.0 <sup>a</sup>	13.4 <sup>a</sup>	10.5 <sup>d</sup>
<b>Winter</b>							
<i>Coprosma robusta</i>	38.0 <sup>b</sup>	7.0 <sup>b</sup>	9.6 <sup>b</sup>	34.1 <sup>a</sup>	24.5 <sup>a</sup>	13.1 <sup>a</sup>	12.2 <sup>a</sup>
<i>Griselinia littoralis</i>	36.3 <sup>b</sup>	6.9 <sup>b</sup>	7.2 <sup>c</sup>	30.6 <sup>a</sup>	20.8 <sup>a</sup>	12.5 <sup>a</sup>	12.2 <sup>a</sup>
<i>Hoheria populnea</i>	41.2 <sup>b</sup>	13.1 <sup>a</sup>	13.5 <sup>a</sup>	36.5 <sup>a</sup>	20.4 <sup>a</sup>	6.6 <sup>b</sup>	10.6 <sup>c</sup>
<i>Pittosporum crassifolium</i>	46.8 <sup>a</sup>	7.3 <sup>b</sup>	7.5 <sup>bc</sup>	38.1 <sup>a</sup>	24.8 <sup>a</sup>	10.1 <sup>ab</sup>	11.6 <sup>b</sup>
<i>Pseudopanax arboreus</i>	41.3 <sup>b</sup>	7.1 <sup>b</sup>	5.6 <sup>c</sup>	21.7 <sup>b</sup>	16.8 <sup>b</sup>	8.7 <sup>b</sup>	12.3 <sup>a</sup>

Note: All the nutrients are expressed as % DM except where indicated.

Nutrient values with different letter superscripts are different at  $p < 0.05$  within a season. Summer samples ( $n = 24$ ), spring ( $n = 24$ ) and winter ( $n = 20$ ). Dry matter (DM), crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF) and metabolisable energy (ME).

### Stem nutritional composition across seasons

The stem nutritional composition was greatly variable (all except CP and lignin) for *H. populnea* and least variable (only CP) for *S. schwerinii* across the seasons (Table 5). Lignin was the only nutritional content that did not differ ( $p < 0.05$ ) across seasons for all the shrub species. The DM did not differ ( $p > 0.05$ ) across seasons for *C. robusta*, *G. littoralis* and *S. schwerinii* but was lower ( $p < 0.05$ ) during the summer season for all the other shrub species. Ash content differed ( $p > 0.05$ ) across seasons only for *H. populnea* and *P. crassifolium* and was higher ( $p < 0.05$ ) in summer and lower ( $p < 0.05$ ) in spring for the two shrub species. The CP was similar ( $p > 0.05$ ) in all seasons for all shrub species except for *C. robusta* and *S. schwerinii*. *Coprosma robusta* CP was higher in winter ( $p < 0.05$ ) and lower ( $p < 0.05$ ) in summer. However, *S. schwerinii* CP was higher ( $p < 0.05$ ) in spring than in summer. The ADF did not differ ( $p > 0.05$ ) in all the seasons for *C. robusta*, *P. arboreus* and *S. schwerinii* but was higher ( $p < 0.05$ ) in winter and lower ( $p < 0.05$ ) and similar ( $p > 0.05$ ) in summer and in spring for all the other shrub species. Native species had higher ( $p < 0.05$ ) NDF which did not differ ( $p > 0.05$ ) between spring and summer seasons. However, the NDF for *H. populnea* and *P. arboreus* in summer was not different ( $p > 0.05$ ) from the other two seasons. *Salix schwerinii* fibre content (ADF and NDF) did not differ ( $p > 0.05$ ) between the summer and spring seasons. The ME did not differ ( $p > 0.05$ ) across seasons for all the shrubs except for *C. robusta* and *H. populnea*. *Coprosma robusta* ME was higher ( $p < 0.05$ ) in winter and lower ( $p < 0.05$ ) in summer, while that for *H. populnea* was lower ( $p < 0.05$ ) in winter than in the other seasons which did not differ ( $p > 0.05$ ).

**Table 5.** Effect of seasons on stem nutritional composition: DM (% wet weight), ash, CP, ADF, NDF, lignin and ME (MJ/kg DM) for the native (*C. robusta*, *G. littoralis*, *H. populnea*, *P. crassifolium* and *P. arboreus*) and exotic (*S. schwerinii*) shrub species.

Species	Season	DM	Ash	CP	ADF	NDF	Lignin	ME
<i>Coprosma robusta</i>	Spring	35.8	6.4	4.7 <sup>ab</sup>	36.7	46.6 <sup>a</sup>	9.1	10.2 <sup>ab</sup>
	Summer	29.4	5.7	4.1 <sup>b</sup>	36.9	47.9 <sup>a</sup>	8.0	9.9 <sup>b</sup>
	Winter	32.3	6.8	6.3 <sup>a</sup>	40.0	30.7 <sup>b</sup>	7.1	10.7 <sup>a</sup>
	SE	2.36	0.24	0.23	1.31	1.31	0.82	0.12
<i>Griselinia littoralis</i>	Spring	32.1	5.6	4.2	38.6 <sup>b</sup>	48.6 <sup>a</sup>	10.2	10.0
	Summer	29.6	5.0	3.4	39.2 <sup>b</sup>	48.6 <sup>a</sup>	12.3	9.9
	Winter	37.0	6.0	3.6	50.9 <sup>a</sup>	40.0 <sup>b</sup>	11.7	9.8
	SE	2.14	0.31	0.41	1.20	1.29	0.33	0.14
<i>Hoheria populnea</i>	Spring	36.0 <sup>ab</sup>	9.0 <sup>b</sup>	8.3	41.5 <sup>b</sup>	53.5 <sup>a</sup>	9.2	9.6 <sup>a</sup>
	Summer	29.0 <sup>b</sup>	10.9 <sup>a</sup>	9.3	35.4 <sup>b</sup>	46.3 <sup>ab</sup>	9.5	9.6 <sup>a</sup>
	Winter	45.5 <sup>a</sup>	9.9 <sup>ab</sup>	8.8	51.6 <sup>a</sup>	41.4 <sup>b</sup>	10.1	8.8 <sup>b</sup>
	SE	4.61	0.80	1.02	4.77	4.52	1.15	0.33
<i>Pittosporum crassifolium</i>	Spring	47.4 <sup>a</sup>	6.7 <sup>b</sup>	4.2	41.0 <sup>b</sup>	52.0 <sup>a</sup>	8.8	9.6
	Summer	35.1 <sup>b</sup>	8.9 <sup>a</sup>	4.8	39.2 <sup>b</sup>	48.3 <sup>a</sup>	9.6	9.5
	Winter	44.7 <sup>ab</sup>	7.4 <sup>b</sup>	4.4	50.3 <sup>a</sup>	38.6 <sup>b</sup>	8.6	9.7
	SE	3.86	0.28	0.19	1.52	1.47	0.45	0.09
<i>Pseudopanax arboreus</i>	Spring	37.1 <sup>a</sup>	9.1	3.6	27.7	37.4 <sup>a</sup>	7.4	10.4
	Summer	26.2 <sup>b</sup>	7.8	2.6	26.5	34.3 <sup>ab</sup>	8.1	10.8
	Winter	33.5 <sup>ab</sup>	8.8	3.5	36.1	28.0 <sup>b</sup>	8.1	10.7
	SE	2.02	0.76	0.37	1.79	1.66	0.60	0.23
<i>Salix schwerinii</i>	Spring	48.5	3.7	7.0 <sup>a</sup>	38.4	48.9	11.6	10.2
	Summer	41.8	3.9	3.8 <sup>b</sup>	40.2	53.3	12.8	10.0
	SE	1.54	0.38	0.67	1.72	1.25	0.34	0.20

Note: All the nutrients are expressed as % DM except where indicated.

Nutrient values for each shrub with different letter superscripts across the seasons are different at  $p < 0.05$ . Summer samples ( $n = 24$ ), spring ( $n = 24$ ) and winter ( $n = 20$ ). SE is Standard error. Dry matter (DM), crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF) and metabolisable energy (ME).

### Comparison of stem nutritional composition among shrubs within seasons

The DM was higher ( $p < 0.05$ ) for *P. crassifolium* than all the other native shrubs that did not differ except for *P. arboreus* in spring (Table 6). There was no difference ( $p > 0.05$ ) in DM for all native shrubs in summer. *Coprosma robusta* had lower ( $p < 0.05$ ) DM than all the other native shrubs which did not differ ( $p > 0.05$ ). However, the DM for *C. robusta* was not different ( $p > 0.05$ ) from that for *G. littoralis* and *P. arboreus* in winter. *Salix schwerinii* had higher ( $p < 0.05$ ) DM than all native shrubs except *P. crassifolium* in both spring and summer seasons. *Hoheria populnea* had higher ( $p < 0.05$ ) ash content than all shrubs in all seasons and only similar ( $p > 0.05$ ) to that for *P. arboreus* in spring and winter. The ash content for *S. schwerinii* was lower ( $p < 0.05$ ) than for all native shrubs in spring and summer except for *G. littoralis* in summer. The CP was higher ( $p < 0.05$ ) for *H. populnea* than for all other shrubs in all seasons. *Salix schwerinii* CP was similar ( $p > 0.05$ ) to that for *H. populnea* in spring and to that for other native shrubs in summer. *Pseudopanax arboreus* had lower fibre content (ADF and NDF) than all the other native shrubs in all seasons except in winter where it was similar to that for *C. robusta*. The fibre content for *S. schwerinii* was higher ( $p < 0.05$ ) and similar ( $p > 0.05$ ) to that for all native shrubs except *P. arboreus* in both spring and summer.

Lignin content was lower ( $p > 0.05$ ) for *P. arboreus* and different only to *G. littoralis* and *S. schwerinii* in spring. *Griselinia littoralis* had higher ( $p < 0.05$ ) lignin in summer than all the other native shrubs which did not differ ( $p > 0.05$ ). During the winter, lignin was higher ( $p < 0.05$ ) for *G. littoralis* and lower ( $p < 0.05$ ) for *C. robusta* than

**Table 6.** Comparison of stem nutritional composition: DM (% wet weight), ash, CP, ADF, NDF, lignin and ME (MJ/kg DM) for the native (*C. robusta*, *G. littoralis*, *H. populnea*, *P. crassifolium* and *P. arboreus*) and exotic (*S. schwerinii*) shrub species within seasons (spring, summer, winter).

Shrub	DM	Ash	CP	ADF	NDF	Lignin	ME
Spring							
<i>Coprosma robusta</i>	35.8 <sup>c</sup>	6.4 <sup>b</sup>	4.7 <sup>b</sup>	36.7 <sup>a</sup>	46.6 <sup>a</sup>	9.1 <sup>abc</sup>	10.2 <sup>ab</sup>
<i>Griselinia littoralis</i>	32.1 <sup>c</sup>	5.6 <sup>b</sup>	4.1 <sup>b</sup>	38.6 <sup>a</sup>	48.6 <sup>a</sup>	10.2 <sup>ab</sup>	10.0 <sup>ab</sup>
<i>Hoheria populnea</i>	36.0 <sup>c</sup>	9.0 <sup>a</sup>	8.3 <sup>a</sup>	41.5 <sup>a</sup>	53.5 <sup>a</sup>	9.3 <sup>abc</sup>	9.6 <sup>b</sup>
<i>Pittosporum crassifolium</i>	47.4 <sup>ab</sup>	6.8 <sup>b</sup>	4.2 <sup>b</sup>	41.0 <sup>a</sup>	52.1 <sup>a</sup>	8.8 <sup>bc</sup>	9.6 <sup>b</sup>
<i>Pseudopanax arboreus</i>	37.1 <sup>bc</sup>	9.1 <sup>a</sup>	3.6 <sup>b</sup>	27.7 <sup>b</sup>	37.4 <sup>b</sup>	7.4 <sup>c</sup>	10.4 <sup>a</sup>
<i>Salix schwerinii</i>	48.5 <sup>a</sup>	3.7 <sup>c</sup>	7.0 <sup>a</sup>	38.4 <sup>a</sup>	48.9 <sup>a</sup>	11.6 <sup>a</sup>	10.2 <sup>ab</sup>
Summer							
<i>Coprosma robusta</i>	29.4 <sup>b</sup>	5.7 <sup>c</sup>	4.2 <sup>bc</sup>	36.9 <sup>a</sup>	47.9 <sup>a</sup>	8.0 <sup>b</sup>	9.9 <sup>b</sup>
<i>Griselinia littoralis</i>	29.6 <sup>b</sup>	5.0 <sup>cd</sup>	3.4 <sup>bc</sup>	39.2 <sup>a</sup>	48.6 <sup>a</sup>	12.3 <sup>a</sup>	9.9 <sup>b</sup>
<i>Hoheria populnea</i>	29.0 <sup>b</sup>	10.9 <sup>a</sup>	9.3 <sup>a</sup>	35.4 <sup>a</sup>	46.3 <sup>a</sup>	9.6 <sup>b</sup>	9.6 <sup>b</sup>
<i>Pittosporum crassifolium</i>	35.1 <sup>ab</sup>	8.9 <sup>b</sup>	4.8 <sup>b</sup>	39.2 <sup>a</sup>	48.3 <sup>a</sup>	9.7 <sup>b</sup>	9.5 <sup>b</sup>
<i>Pseudopanax arboreus</i>	26.2 <sup>b</sup>	7.8 <sup>b</sup>	2.6 <sup>c</sup>	26.5 <sup>b</sup>	34.3 <sup>b</sup>	8.1 <sup>b</sup>	10.8 <sup>a</sup>
<i>Salix schwerinii</i>	41.8 <sup>a</sup>	3.9 <sup>d</sup>	3.7 <sup>bc</sup>	40.2 <sup>a</sup>	53.3 <sup>a</sup>	12.9 <sup>a</sup>	10.1 <sup>b</sup>
Winter							
<i>Coprosma robusta</i>	32.3 <sup>b</sup>	6.8 <sup>c</sup>	6.3 <sup>b</sup>	40.0 <sup>b</sup>	30.7 <sup>bc</sup>	7.1 <sup>c</sup>	10.7 <sup>a</sup>
<i>Griselinia littoralis</i>	37.0 <sup>ab</sup>	6.0 <sup>c</sup>	3.6 <sup>c</sup>	50.9 <sup>a</sup>	40.0 <sup>a</sup>	11.7 <sup>a</sup>	9.8 <sup>b</sup>
<i>Hoheria populnea</i>	45.5 <sup>a</sup>	9.9 <sup>a</sup>	8.8 <sup>a</sup>	51.6 <sup>a</sup>	41.4 <sup>a</sup>	10.1 <sup>ab</sup>	8.8 <sup>c</sup>
<i>Pittosporum crassifolium</i>	44.7 <sup>a</sup>	7.4 <sup>bc</sup>	4.4 <sup>bc</sup>	50.3 <sup>a</sup>	38.6 <sup>ab</sup>	8.6 <sup>bc</sup>	9.7 <sup>b</sup>
<i>Pseudopanax arboreus</i>	33.9 <sup>ab</sup>	8.9 <sup>ab</sup>	3.6 <sup>c</sup>	35.8 <sup>b</sup>	27.7 <sup>c</sup>	8.2 <sup>bc</sup>	10.7 <sup>a</sup>

Notes: All the nutrients are expressed as % DM except where indicated.

Nutrient values with different letter superscripts are different at  $p < 0.05$  within a season. Summer samples ( $n = 24$ ), spring ( $n = 24$ ) and winter ( $n = 20$ ). Dry matter (DM), crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF) and metabolisable energy (ME).

other native shrubs. Lignin content for *S. schwerinii* was higher ( $p < 0.05$ ) and similar ( $p > 0.05$ ) to that for all native shrubs except *P. crassifolium* and *P. arboreus* in spring and did not differ ( $p > 0.05$ ) to that for *G. littoralis* in summer. The ME was higher ( $p < 0.05$ ) for *P. arboreus* and lower ( $p < 0.05$ ) for *H. populnea* and *P. crassifolium* in spring. *Pseudopanax arboreus* ME was higher ( $p < 0.05$ ) than all native shrubs that did not differ ( $p > 0.05$ ) in summer and was higher ( $p < 0.05$ ) and similar ( $p > 0.05$ ) to that for *C. robusta* in winter. Stem ME for *S. schwerinii* did not differ ( $p > 0.05$ ) from that for native shrubs in spring and similar ( $p > 0.05$ ) to native shrubs except *P. arboreus* in summer.

## Discussion

This study sought to evaluate and compare the nutritional composition of the leaf and edible stem components of five native shrubs and an exotic osier willow (*S. schwerinii*) across and within the seasons. The five native shrubs are endemic to New Zealand and often found on reserves and unutilised parts of hill country sheep and beef cattle farms. They are known to be palatable and browsed by wild herbivores (Bee et al. 2011). *Salix schwerinii* has been used in hill country sheep and beef cattle farms primarily for soil conservation and also as a source of supplementary fodder (Douglas et al. 2009). It is possible that native shrubs could be used for the same purpose. A bioeconomic modelling study (Wangui et al. 2021) suggested that if native shrubs are used in this manner they can provide sufficient supplemental forage for sheep, especially during summer when pasture quality is low and potentially increase farm income. However, the estimation of herbage production in this model was based on sparse data available (Wangui et al. 2021). It is known that sheep will browse *S. schwerinii* leaf and stem up

to 5 mm in diameter (Pitta et al. 2009). Therefore, it is of benefit to gain a greater understanding of the nutritional composition of native shrub leaf and stem to determine their potential use as supplemental forage on hill country sheep and beef farms in New Zealand.

### **Seasonal variation in leaf nutritional composition**

The shrubs nutritional composition differences across the seasons can be attributed to phenological responses to seasonal changes (Chapman et al. 2014). These responses influence leaf growth and senescence affecting nutrient assimilation and mobilisation causing the observed nutritional composition variability across the seasons (Chapman et al. 2014). Phenologically, *S. schwerinii* is deciduous (Brereton et al. 2014) while the native shrubs in this study are evergreen (Metcalf 2011). The DM for *S. schwerinii* was unaffected by seasons. However, native shrub DM was higher in winter, lower in summer and showed inconsistencies in spring. The similar DM for *S. schwerinii* in spring and summer could have resulted because the foliage leaves sampled in the spring season were already expanded. The lower DM in native shrubs during summer can be explained by the warming and lengthening photoperiod in summer, which increases photosynthetic activity and cellular turgidity (González-Zurdo et al. 2016).

Higher CP was observed in *S. schwerinii* in spring compared to summer, while CP remained consistent across seasons for most native shrubs. This higher spring CP in *S. schwerinii* results from increased nitrogen mobilisation from perennating organs to growing leaves (Brereton et al. 2014). In contrast, leaf senescence in native species likely results in mixed leaf ages across seasons (González-Zurdo et al. 2016). The physiological process in evergreen shrubs involves transferring nitrogen from old to new leaves (González-Zurdo et al. 2016), explaining the consistent CP across seasons for most native shrubs.

Although structural leaf cell wall content varied across seasons for both *S. schwerinii* and native shrubs, the trend was different. For *S. schwerinii*, leaf structural cell wall content increased from spring to summer, likely because juvenile leaves in spring matured and accumulated more structural cell wall components by summer (González-Zurdo et al. 2016). In contrast, native shrubs had higher ADF in winter and lower in spring and summer, with the opposite trend for NDF. Increasing temperatures and photoperiod from spring through summer trigger new leaf growth, which is lower in ADF and higher in NDF, with the inverse trend in winter (González-Zurdo et al. 2016).

Additionally, González-Zurdo et al. (2016) showed that increased ADF and NDF is an adaptive response of evergreen plants to cold temperatures and short photoperiods in winter, as observed in this study. However, lignin content remained constant across the seasons for all native shrubs, likely because lignin is a major structural component that maintains leaf rigidity (González-Zurdo et al. 2016), and sampled leaves were of mixed ages across seasons. In both *S. schwerinii* and native species, ME was higher in spring than in summer, which is expected because ME is inversely related to structural cell wall contents (Waghorn 2007).

Forages should contain CP above 7% DM for normal rumen microbial activity (Yang et al. 2018) and over 10% DM to meet ruminants maintenance requirements (Hynd 2019). *Salix schwerinii* leaves had higher CP than native shrubs in spring but were

similar in summer. This suggests *S. schwerinii* leaf CP can meet ruminant maintenance requirement in spring and support microbial activity in summer as a sole diet. The summer CP for *S. schwerinii* in this study was consistent with findings by Oppong et al. (2002) and McWilliam et al. (2004) but lower than reported by Douglas et al. (1996). Except *H. populnea*, all native shrubs had CP below maintenance requirements for ruminants in all the seasons. *Pseudopanax arboreus* had CP below the minimum needed for rumen microbial activity in all seasons, while *G. littoralis* and *P. crassifolium* were below this threshold in spring and summer. The CP for native shrubs other than *H. populnea* was lower than common pasture species (perennial ryegrass, red clover, plantain and chicory) in New Zealand (Kemp et al. 2014; Pain et al. 2015; Dalley et al. 2017; Litherland and Lambert 2017) in all seasons. *Hoheria populnea* CP was lower than Tagasaste, broom and black locust, but within the range for tree medic, gorse and ceanothus and higher than for Manuka and Tauhinu (Lambert et al. 1989).

Neutral detergent fibre measures the total fibre content in forages including the digestible (hemicellulose) and less digestible ADF (cellulose and lignin) components (Hynd 2019). The NDF is highest in new growth and decreases as ADF constituents are added with maturity for structural rigidity. Both ADF and NDF are essential for rumen functioning and energy supply to ruminants (Pain et al. 2015; Hynd 2019). Levels of ADF and NDF below 20% DM and 30% DM or above 50% DM and 70% DM, respectively, can compromise forage digestibility and utilisation by ruminants (Hynd 2019). All shrubs had ADF and NDF within acceptable ranges for grazing animals except *P. arboreus*, which was lower in all seasons. Except for *P. arboreus*, the ADF and NDF of all shrubs were comparable to common pasture species (perennial ryegrass, red clover, plantain, and chicory) (Kemp et al. 2014; Pain et al. 2015; Dalley et al. 2017; Litherland and Lambert 2017) and forage shrubs (Vandermeulen et al. 2018) in New Zealand. The ADF and NDF for *P. arboreus* were within the ranges reported for fodder supplements (brassica, rape, swedes, beets, and turnips) used in New Zealand (De Ruiter et al. 2007; Guevara-Escobar et al. 2007; Dalley et al. 2017; Litherland and Lambert 2017).

Most native shrubs were superior to *S. schwerinii* in ME in all seasons and were within the ranges reported for fodder supplements (brassica, rape, swedes, beets, and turnips) (De Ruiter et al. 2007; Guevara-Escobar et al. 2007; Dalley et al. 2017; Litherland and Lambert 2017) and higher than for common pasture species (Kemp et al. 2014; Pain et al. 2015; Litherland and Lambert 2017) used in New Zealand. However, the ME for *H. populnea* and *S. schwerinii* were within the ranges reported for hill country pastures (McWilliam et al. 2005; Guevara-Escobar et al. 2007; Pain et al. 2015). The ME for *S. schwerinii* in this study was higher than reported for foliage (leaves plus stems < 5 mm diameter) in summer and lower than the average for willow and poplar foliage in spring and summer (Kemp et al. 2003).

### **Seasonal variation in stem nutritional composition**

Stem nutritional composition was relatively stable but below the minimum requirements for rumen microbial activity (Yang et al. 2018). The CP was lower than for common pasture species and supplement fodder crops (Kemp et al. 2014; Pain et al. 2015;

Litherland and Lambert 2017) but within the range reported for hay and straws (Dalley et al. 2017) in New Zealand. *Salix schwerinii* had similar fibre content and ME with all the native shrubs except for *P. arboreus* in spring and summer seasons. The fibre contents for the shrubs were comparable to summer pastures (Pitta et al. 2009) and lower than for forage shrubs (Lambert et al. 1989) in New Zealand. Additionally, the ME for all shrubs was higher than for summer pastures (Pitta et al. 2009).

Stem nutritional composition varied more across seasons for native shrubs than for *S. schwerinii*. *Salix schwerinii* stems only varied in CP between spring and summer while the native shrubs showed variability in fibre contents except lignin across the seasons. The decrease in CP for *S. schwerinii* between spring and summer could be due to the increased mobilisation of nitrogen from the stem reserves to the growing foliage and catkins formation (Brereton et al. 2014). However, variation in fibre content for the native shrubs can be attributed to their physiological response to seasonal changes in weather conditions (González-Zurdo et al. 2016).

The low stem DM in spring and summer indicates that native shrub stem cells were more turgid, likely due to new growth due to increased photosynthetic activity with increasing temperature and photoperiod (Tanaka et al. 2015). This new growth explains the higher NDF in spring and summer and lower NDF in winter, with the opposite trend for ADF (González-Zurdo et al. 2016). Although new stem growth occurred in spring and summer for all the shrubs, the sampled stems contained woody portions explaining the invariable lignin across the seasons (González-Zurdo et al. 2016). Generally, stem ME for most of the shrub species was unaffected by the season likely due to the high structural cell wall content of the stems (Waghorn 2007).

### **Comparison of *Salix schwerinii* to native shrubs as potential forage**

In New Zealand, climatic conditions can support year-round pasture production, but both the quantity and nutritional composition fluctuate with seasonal weather changes (Waghorn and Clark 2004). Pasture nutritional composition on hill country sheep and beef cattle farms varies more in summer on steep slopes due to soil moisture deficits and poor soil fertility (Kemp and Lopez 2016). Hill country summer pastures often contain CP >10% DM (Dove 2010; Litherland and Lambert 2017) but have low ME (<10 MJ/ kg DM) (Pitta et al. 2009; Nicol and Brookes 2017). Willows and poplars foliage contain higher ME than pastures in summer and are often used as supplementary fodder (Pitta et al. 2009). Comparison of *S. schwerinii* with the five native shrubs has revealed that while native shrub leaves have superior in ME (>10 MJ/ kg DM), their stems nutritional composition is generally comparable. However, native shrubs except for *H. populnea* have lower CP than *S. schwerinii* in spring but are comparable in summer. Unlike other native shrubs, *H. populnea* was comparable to *S. schwerinii* in ME but was superior to *S. schwerinii* in CP during summer. Additionally, native shrubs contain lower structural cell wall contents than *S. schwerinii* in summer suggesting they would be more digestible. Previous studies have also reported higher digestibility of native shrubs compared to *S. schwerinii* (Wangui et al. 2022). Comparing *S. schwerinii* with native shrubs demonstrates that native shrubs can be potential sources of fodder to supplement the low ME found in summer pastures. Moreover, native shrubs can provide herbage during winter because they are evergreen unlike to *S. schwerinii*.

## Conclusion

The findings from this study show that native shrub leaves contain superior ME than *S. schwerinii* and pastures in summer. In addition, *S. schwerinii* and native shrub leaves and stems contain ADF and NDF within ranges acceptable for ruminants. However, the native shrubs except for *H. populnea* have lower CP than can meet the maintenance requirements of grazing animals in all seasons. Therefore, native shrubs can be a potential supplementary fodder in winter when pasture quantity is low to provide herbage and during the summer when pasture quality is poor to provide ME. However, additional studies to determine native shrub intake and preference by sheep are recommended.

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## Author contributions

Conceptualisation, JC., PK., PT., JM., GS. and SP.; methodology and statistics, JC., PK., PT., JM., GS. and SP.; results review and validation, JC., PK., PT., JM., GS. and SP.; writing- original draft preparation, JC.; writing- review and editing, PK., PT., JM. and SP.; supervision, PK., PT., JM. and SP. All authors have read and agreed to the published version of the manuscript.

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