Final report

BeefLinks: Defining the potential and application of (native) Australian plants for a carbon neutral northern beef value chain in Western Australia

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Prepared by: Zoey Durmic, Peter Hutton, Philip Vercoe, Julian Hill
The University of Western Australia, Ternes Scientific

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Meat & Livestock Australia Limited
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Abstract

Consumer demand in developed countries is shifting towards pasture grown beef and Australia is well placed to support this market. However, there is concern for the negative impact that grass-fed red meat production has on global warming because of greenhouse gas emissions by ruminant livestock from the microbial fermentation of high fibre diets. An understanding of the anti-methanogenic attributes of the feed base was investigated using *in vitro* technology. This approach has been previously used to rank feeds of differing anti-methanogenic properties and provided producers a list of candidates that could be deployed within an existing feed base or when rejuvenation of the feed base was undertaken. Key plant species were identified with the potential to reduce methane emissions from cattle and improve animal performance. However, the high establishment risk/low return of pasture establishment in the semi-arid regions of Western Australia is likely to move producers towards species protection rather than pasture establishment. The Western Australia beef industry has the opportunity of addressing the increasing global demand for red meat while becoming a carbon neutral value chain.

Executive summary

Background

Global demand for red meat is increasing each year and there are opportunities for Australian contributions to this market. Consumer demand in developed countries is shifting towards pasture grown beef and Australia is well placed to support this market. However, there is concern for the negative impact that grass-fed red meat production has on global warming because of greenhouse gas emissions by ruminant livestock from the microbial fermentation of high fibre diets.

Considerable work has been undertaken over the last decade to understand the role of the feed base in abating livestock methane production through changes in emissions intensity or through direct abatement of rumen methanogenesis. Much of that work was conducted with the intention of understanding baseline methane emissions from grazing livestock and the design of new feed base scenarios that could be simply established, maintain productivity whilst reducing overall farm greenhouse gas emissions. Research in WA focused initially on understanding baseline emissions from southern livestock systems (predominantly sheep production), the range of antimethanogenic activity in plants from the WA southern and central rangelands and pastoral regions, and the potential integration of antimethanogenic shrubs into existing wheat sheep production systems. The current work builds on these studies and is focused on the knowledge gap for northern production systems – are there species of plants endemic to the central and northern WA rangelands that have antimethanogenic properties and could those candidate species be made available as part of the feed base for producers in the northern rangelands. These environments have never been evaluated.

An understanding of the anti-methanogenic attributes of the feed base can be investigated using *in vitro* technology. This approach has been previously used to rank feeds of differing anti-methanogenic properties and provided producers a list of candidates that could be deployed within an existing feed base or when rejuvenation of the feed base was undertaken (https://www.mla.com.au/research-and-development/reports/2023/ffi-future-farms-crc/"https://www.mla.com.au/research-and-development/reports/2023/ffi-future-farms-crc/; and ENRICH-2 https://www.mla.com.au/contentassets/7af5de356b3d4396a4930de2bcad3179/b.pas.0236_final_report.pdf). This has not been done for the northern WA mosaic feedbase that supports beef production down the supply chain, which is the focus of this project. The results from this project will be used to expand current knowledge and farm guides developed in ENRICH to northern and central WA rangeland environments. This delivery of new knowledge aims to assist producers move towards understand which species are present, grazed / utilized by livestock, how those species may reduce rumen methane emissions and thereby assist producers to develop new strategies resulting in carbon neutral and profitable supply chain for the beef industry of northern Western Australia. Furthermore the project will assist producers in developing, where necessary, statements focused on natural capital management and fulfil emerging biodiversity policy statements.

Objectives

The objectives of this project were to:

- to quantify the diversity in anti-methanogenic and productivity properties (nutritional value) of naturally occurring, and a number of commercially available, plant species that make up the feedbase of northern WA mosaics used for beef production.
- this objective was met, although, a more comprehensive library of data that includes all plant species available to livestock would add value for producers.
- to investigate the potential to extend the range of target plant species into southern systems and deliver a consistent grazing diet mitigation approach.
- this objective was met using the initial database search that targeted species from central and southern regions of northern Western Australia. These species are potentially suited to southern systems.
- to report options for producers to adopt anti-methanogenic feed bases.
- This objective was met via a series and grower group meeting where information was disseminated. A set of guidelines were produced from the collated data.

Methodology

The project created a specific database to capture a range of plant species with target parameters. A strategic approach was needed because of the large number of plant species present in Western Australia (>11,000 species) and in the northern bioregions, and the complexity of the information that is available.

The plants were collected from participating IBRA stations and tested in vitro for their fermentation characteristics and nutritive values. A database was built from the analyses.

The effect of site location and sampling date (sesonality) were also detyermined through interrogation of the in vitro and nutritive value databases representing repeat sampling at known locations with known species.

The effect of seasonality was assessed on ten key species and ten species at Hamersley station, Pilbara, NW WA.

Three rumen simulation technique (RUSITEC) experiments were used for a more comprehensive analysis of potent species.

Guidelines were produced and benefit cost analysis and cost realisation adoption modelling were used to assess the likely implementation by producers of desirable species into their enterprises.

Results/key findings

Key plant species were identified with the potential to reduce methane emissions from cattle and improve animal performance. Combining key species in a “mixed diet” *in vitro* further improved the fermentation profiles. Nutritive values of species varied between location and season, but species identified as methane inhibitors maintained the inhibitory effect across space and time. The high establishment risk/low return of pasture renovation in the semi-arid regions of Western Australia is likely to limit adoption by producers.

Benefits to industry

This work is valuable for the direct abatement of methane emissions of northern cattle through targeted grazing management of key plant species. A large diversity in plant species was identified with anti-methanogenic and desirable nutritive characteristics. It is critical to continue adding to the knowledge of the feed base that comprises the diet of rangeland cattle in Western Australia.

The benefits to the wider red meat industry include consistency of production by focussing on the management of key species across the supply chain. The potential for methane abatement is high from the array of bioactive plant species identified. The Western Australia beef industry has the opportunity of addressing the increasing global demand for red meat while becoming a carbon neutral value chain.

Future research and recommendations

Future work must focus on continued development of the database library. Projects that focus on technologies to identify key species in the diet will allow rapid improvement of the feed base. Practical application of the data generated from the project should focus on two main areas. First, the application of key species identified in the guidelines to individual scenarios. Second developing strategies to implement species preservation and regeneration for profitability. BEEFLINKS projects such as Virtual Fencing (P.PSH.1306) offer a high potential for the practical grazing management of desirable species.

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1. Background

1.1 Purpose and description

Previous investments by MLA (B.CCH.1012 & B.CCH.1024) have examined the anti-methanogenic characteristics of the southern rangelands feed base in Western Australia. The data from this project provides producers a range of feed base options that support the drive for methane abatement from beef cattle as well as the drive for a carbon neutral value chain. One gap in knowledge is the anti-methanogenic feed base options available for beef producers in the northern rangelands. These environments have never been evaluated. The previous MLA investments in developing an understanding of the anti-methanogenic attributes of the feed base have focused on using a range of technologies (in vitro, RUSITEC and in vivo). This approach was demonstrated to rank feeds of differing anti-methanogenic properties and provided producers list of candidates that could be deployed within an existing feed base or when rejuvenation of the feed base was undertaken. Further, research on the impact of spatial arrangement of anti-methanogenic forage options and choice selection by the animal was undertaken to provide practical solutions for pasture management and design of feed supply and allocation for sheep production systems. This has not been done for the northern WA mosaic feed base that supports beef production down the supply chain, which is the focus of this project.

The objective of this project is to quantify the diversity in anti-methanogenic and productivity properties of several commercially available, and naturally occurring plant species that make up the feed base of northern WA mosaics used for beef production. Many of these species may have the potential for greater adoption because they reduce methane emissions directly and/or emissions intensity through improved efficiency of livestock production, and thereby driving the industry towards carbon neutrality.

Using both the in vitro data from this project and links animal production-based experimentation (P.PSH.1245 and P.PSH.1233) we validated the properties of these pasture species to reduce methane and emissions intensity and develop pasture management guidelines that complement diet selection and ultimately assist in land management that mitigates GHG emissions.

1.1.1 The value of native and naturalised plants to extensive grazing systems

Global demand for red meat is increasing at ~1.5% each year (FAO, 2017) and there are opportunities for increasing Australian contributions to this market. Consumer demand in developed countries such as the USA is shifting towards pasture grown beef and Australia is well placed to support this market (Hayek and Garrett, 2018). However, there is concern for the negative impact that grass-fed red meat production has on global warming because of greenhouse gas (GHG) emissions by ruminant livestock from the microbial fermentation of high fibre diets (Davison et al., 2020). Agricultural GHG emissions have risen by ~20% since 1990, largely due to the increased demand for ruminant products and the associated enteric methane emissions (IPCC, 2022). Methane is a potent GHG with up to 28 times more warming potential than carbon dioxide (IPCC, 2014). Although more potent than carbon dioxide, methane dissipates relatively quickly from the atmosphere (~ 9 years) compared to carbon dioxide (~100 years) (Saunois et al., 2020). Options for reducing methane emissions are therefore recognized for rapid climate change mitigation, especially on decadal timescales because of its shorter lifetime than carbon dioxide.

The shift towards pasture grown beef will continue because production from pastures and rangelands requires a third of the fossil fuel compared with feedlot production (Kunstler, 2005). Grazed plants will become important for their primary compounds (nutrients) and secondary compounds (pharmaceuticals) for nutrition, health and potentially methane reduction (Provenza, 2008). Australian plants have evolved in arid landscapes with infertile soils and low and variable rainfall to become thrifty in their use of limited resources. Energy can be partitioned away from growth and towards secondary compounds that deter herbivory and insect attack (Kriedemann et al., 1999). Many of these compounds have been found to have antimicrobial properties and have been used in traditional healthcare for thousands of years (Palombo and Semple, 2001). Australian plants have been observed to contain plant secondary compounds (PSC) that can modulate fermentation in the rumen (Hutton et al., 2012, Hutton et al., 2010), improve the efficiency of digestion in the rumen, thereby reducing methane formation per unit of digestible matter (Avila et al., 2020, Waghorn and McNabb, 2003) or directly target methanogens (Wanapat et al., 2012, Banik et al., 2016, Durmic et al., 2010).

Rangeland beef production is the dominant agricultural activity in northern Western Australia, with approximately 23% of the Pilbara bioregion under pastoral leases and 65% of this dedicated to grazing (Annon., 2008, Clunies-Ross and Mitchell, 2014). Dominant pasture types are Mitchell grass, Acacia woodland, Blue grass, hummock (spinifex) and tussock grasslands in the northern rangelands, and shrublands in the south (DAFWA, 2019, DPIRD, 2019). In the southern part of the Pilbara livestock graze mostly across mulga shrubland pastures that have tall shrubs of *Acacia* with various smaller shrubs as understorey, while stony chenopod pastures have low palatable saltbush species (Bortolussi et al., 2005, Clunies-Ross and Mitchell, 2014, Payne and Mitchell, 2002). However, the rangelands are comprised of a much more complex mosaic of plant species that make up the diet of grazing cattle. Locally adapted animals learn nutritional wisdom from their mothers and are known to select a variety of plants that can include those low in primary nutrients but high in secondary compounds that modulate rumen function (Provenza, 2008). Overall, the ability of Western Australian rangeland cattle to select plants with beneficial properties for growth and well-being is not well understood.

In Western Australia there are over 12,000 plant taxa listed and described in Florabase, the Department of Biodiversity Conservation and Attractions (DBCA) database (https://florabase.dpaw.wa.gov.au/). Although the diversity is well described, there has been little work done on the nutritional values or bioactive properties of most of these species. It would be beneficial to the northern Australian beef industry to use the broad database to investigate species that have the potential to be useful in cattle production systems. Increasing our knowledge of rangeland plants will improve our understanding of grazing behaviour, grazing management and species conservation.

If Australia is to be part of the solution for increasing demand for red meat production the issue of greenhouse gas emissions must be addressed. The Carbon Neutral 2030 (CN30) initiative has shown the possibility of a carbon neutral red meat industry (Davison et al., 2020). Within the CN30 initiative the BeefLinks CN30 project that aims to define the potential and application of Australian plants for a carbon neutral northern beef value chain in Western Australia.

The objectives of the BeefLinks CN30 project were to;

- collate a database of key plant species that form the mosaic of plant species in the traditional Australian Bioregions (IBRA) of Western Australia
- initiate an assessment of the nutritional values (chemical and fermentative) and bioactive properties (antimethanogenic) of selected naturally occurring plant species of the northern WA rangeland mosaics.
- determine nutritive and bioactive variation within species across locations and seasons.

The expectations were that plant species would be identified with the potential to improve animal production (increase gas and VFA) and efficiency (reduce ammonia) and reduce greenhouse gases (methane).

2. Objectives

The project aims to provide new knowledge and opportunities that harness direct abatement through targeted grazing management strategies for the northern feed base and north-south alliance properties:

- to quantify the diversity in anti-methanogenic and productivity properties (nutritional value) of naturally occurring, and a number of commercially available, plant species that make up the feedbase of northern WA mosaics used for beef production.
- to investigate the potential to extend the range of target plant species into southern systems and deliver a consistent grazing diet mitigation approach.
- to report options for producers to adopt anti-methanogenic feedbases.

3. Methodology

3.1 Approach

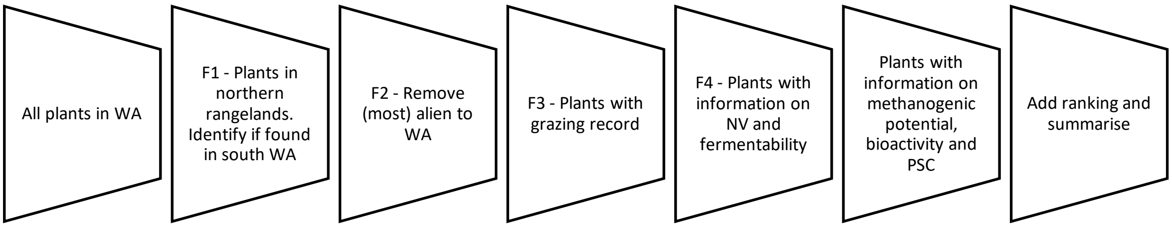
A data base of diverse candidate plant species was formed and over 100 of these were collected from eight stations across the central and southern regions of the northern rangelands of Western Australia. Botanical specimens were collected for identification at the WA herbarium. Fermentative characteristics (methane and total gas production) were determined in-house using a batch fermentation technique and nutritive profiles by near infrared spectrophotometry (NIRS).

A subsample of species was collected from multiple stations to determine the effect of location on plant characteristics. Ten key species were located Hamersley station and assessed over two years – two wet and two dry seasons - to determine the effect of season on fermentation profiles and nutritive values. Promising species were assessed in more detail using a series of RUSITEC experiments to determine the persistency of effect over time. The data was collated, and a set of guidelines formed to assist producers to adopt practice changes to reduce greenhouse gas emissions from the northern agricultural region. A benefit cost and benefit realization analyses were used to assess the likely adoption by producers of reseeding areas of their stations to desirable plant species identified in the project.

3.1.1 Database of target species

We created a specific database to capture a range of species with target parameters. A strategic approach was needed because of the large number of plant species present in Western Australia (>12,000 species) and in the northern bioregions, and the complexity of the information that is available. We used a comprehensive list of candidates and eliminated species by applying selection criteria (Fig. 1). As general criteria, we focused on Australian natives and those found within Interim Biogeographic Regionalisation for Australia (IBRA)regions of the northern rangeland that may contribute to the fodder base of beef production and/or offer methane mitigation. We reduced the list only to those present in the northern and central rangelands (Filter 1, F1), removed alien (but not naturalised) and weed species to WA (F2), limited species with economic or grazing value based on literature searches, information from station manager and staff and agronomist expertise (F3), identified reported nutritive values (NV) or fermentation characteristics (F4). The list was further populated with information (where available) on their anti-methanogenic properties, and any reported bioactivity or presence of plant secondary compounds. Finally, we introduced a ranking system to selected columns and assign ranking 1 – 5 (1 being excellent, desirable and 5 being poor, undesirable) for Grazing value, palatability, fodder potential /Digestibility, NV/Fermentability (gas)/CH_4 mitigation potential. We also considered ability of species to grow both in north and south of WA to target the Objective 2.

Figure 1. Process used to generate CN30 database



3.1.2 *In vitro* analysis

The *in vitro* fermentability and methane production testing was conducted in-house, using *in vitro* batch fermentation technique modified for analysis of Australian forage plants (Durmic et al., 2010). Briefly, 0.1 g of plant sample was incubated with 10 mL of buffered rumen fluid in a Bellco tube for 24 h at 37^{o}C. At the end of incubation period, gas production was measured using a pressure transducer, while methane was analysed using gas chromatography. Liquid portion was analysed for concentrations of VFA and NH_3 at Animal Health Laboratories of the Department of Primary Industries and Regional Development (DPIRD), based in South Perth.

The RUSITEC experiments were conducted in-house, as per published protocols adapted for testing Australian forage plants (Li et al., 2014, Ghaffari et al., 2015). Briefly, the experiment ran for 22 days, with the first 7 days of adaptation of the system and using oaten chaff as substrate, then introducing treatments and running for another 15 days (treatment period). Treatments (n=5) were in triplicate (three fermenters), and each substrate bag was fermented for 48 h before being replaced with a fresh bag. During treatment period, pH, gas, methane was measured daily, while digestibility, VFA and NH_3 concentrations were measured every three days.

The nutritive profiles were determined by NIRS scanning outsourced to CSIRO Floreat. Briefly, spectra were collected on a FOSS XDS Rapid Content™ Analyzer (FOSS Analytical, Hilleroed, Denmark). All samples were analysed in the range of 400–2500 nm with a spectral resolution of 0.5 nm. Spectra were acquired with ISIscan™ Routine Analysis Software (Foss, Denmark). Samples were presented to the NIR in circular quartz sample cups, non-rotating, with a minimum sample diameter of 21.6 mm and scanned sample area of 233.7 mm^2. Samples were repacked and scanned in duplicate, and the average spectrum for each sample was used for subsequent calibrations and predictions. NIR calibration models were established using WinISI software version 4.8.0 (FOSS Analytical A/S, Denmark). The ranges and means for the six nutritional parameters (ASH, CP, EE, aNDF, ADF and ADL) of plant species (Norman et al., 2020).

The methodologies used were appropriate and effective at characterising the methanogenic and nutritive potential of the diverse northern rangeland feedbase. The diversity of species was represented by a mix of grass, herb, shrub and tree species. The simple batch fermentation technique is effective for screening large numbers of plant species relatively quickly and cheaply. It would be ideal to extend this work to build a more comprehensive library for the Western Australian feedbase.

4. Results

4.1 Overview

The database from the literature search of plant candidates and the fermentability and nutritive values are included in 8.1.1, Appendix I. An example of the data is provided in Table 1 representing sampling from Hamersley Station, Pilbara, NW WA. These data link closely to other research activities at the site over the period 2021-2022 (for instance P.PSH.1306)

The most potent inhibitor of methane was *Eremophila fraseri* which also produced higher than average metabolizable energy and crude protein values. *Ptilotus exaltatus* was consistently highest in nutritive values, was moderately to highly fermentable and varied in its effect on methane formation. Grass species such as *Themeda* are preferred by cattle for their high fibre content. *Themeda* sp. Hamersley consistently tested lower for fermentability and metabolizable energy due to high fibre content but interestingly tended to reduce methane formation compared with the high fibre control. The low crude protein of *Themeda* sp. Hamersley means that, to meet daily protein requirements cattle need to seek higher protein species such as annual shrubs including *Solanum lasiophyllum* and *Ptilotus exaltatus* when they are available or more consistently, deep rooted perennial species including trees such as *Acacia pruinocarpa.*

Eremophila species were described as having low grazing preference but were often observed to be potent for methane reduction. Consequently, *Eremphila* was identified as having potential for compound extraction for use as feed additives (serrulatane diterpenes).

Table 1. Fermentation characteristics of target plant species at Hamersley station, Pilbara between wet and dry seasons in 2021 and 2022. Species are placed into methane and gas production categories according to 2021 wet season results. Means by season that do not share a common superscript differ (P<0.05). NT- no test due to absence of the plant.

	Gas volume (mL/g dry matter)				**Methane (g/kg DM)**			
Season	Wet 2021	Dry 2021	Wet 2022	Dry 2022	Wet 2021	Dry 2021	Wet 2022	Dry 2022
Control: Avena sativa (oaten chaff)	342	311	327	343	19.5	16.7	16.3	17.9
Reduced methane								
Eremophila fraseri	314	281	242	267	2.0	1.4	0.3	1.5
Solanum lasiophyllum	324	281	292	292	8.3	6.2	7.7	5.2
Acacia pruinocarpa	303	270	278	284	10.4	7.9	12.3	8.9
Themeda sp. Hamersley	311	286	288	291	11.5	11.0	9.7	8.7
Reduced methane, maintained gas production								
Ptilotus exaltatus	326	296	267	333	11.2	8.7	1.7	19.5
Maintained gas production								
Cleome/Arivela viscosa	356	309	NT	305	11.2	13.9	NT	9.8
Ptilotus obovatus	346	326	332	322	13.1	17.2	17.3	16.3
Vachellia farnesiana	347	319	318	333	17.8	14.3	17.5	14.5
Urochloa gilesii ssp. occidentalis	339	312	318	305	19.1	14.9	18.8	12.2
Triordia wiseana	304	291	279	283	11.5	12.3	8.0	7.1
Average	**326**	**297**	**292**	**304**	**11.6**	**10.6**	**10.0**	**10.4**
sig	a	b, c	c	b	ns	ns	ns	ns

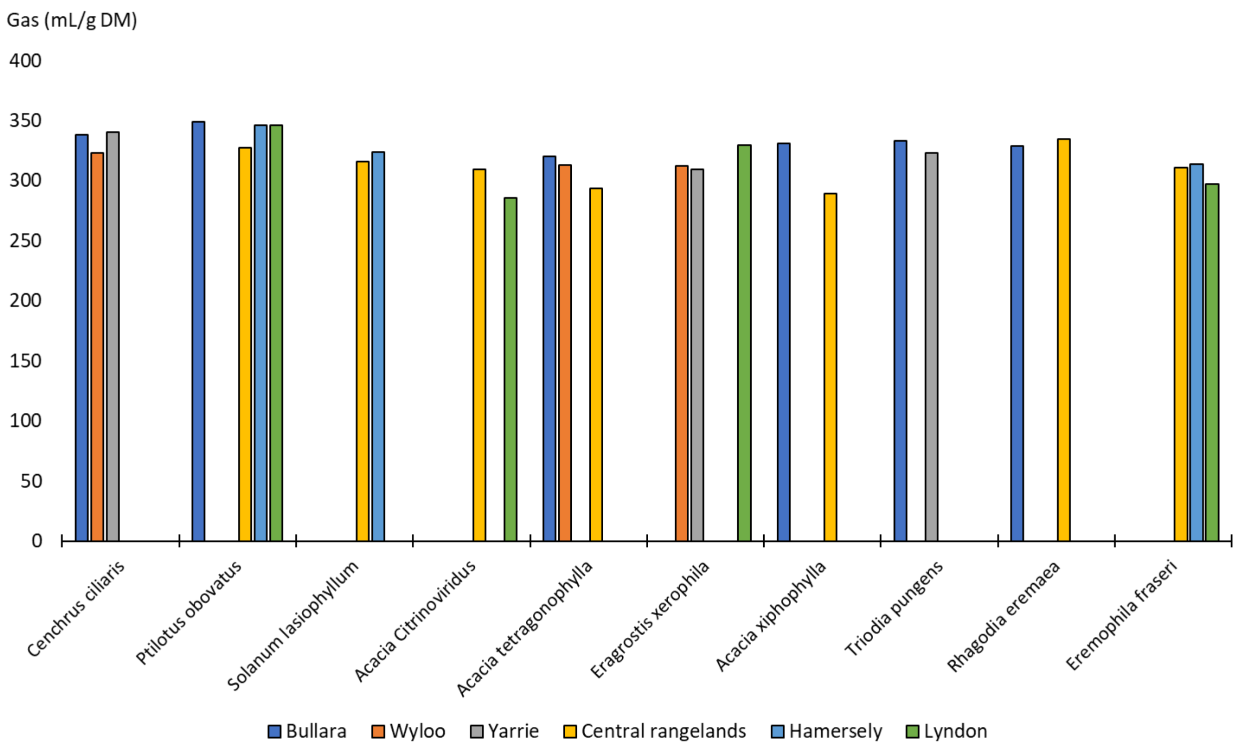
4.1.1 The effect of location on fermentation characteristics

The variation in the gas production within the same species and across different stations/regions was relatively small (i.e. 6%) (Fig. 2.). The largest such variation was observed with *Acacia xiphophylla* (13%) between Hamersely and the Central Rangelands. This could potentially be explained by differences in the environmental factors such as rainfall or soil type, or even by some within species differences such as plant accession, leading to different chemical composition of the plant, resulting in different fermentative traits, but further studies are needed and across a range of species.

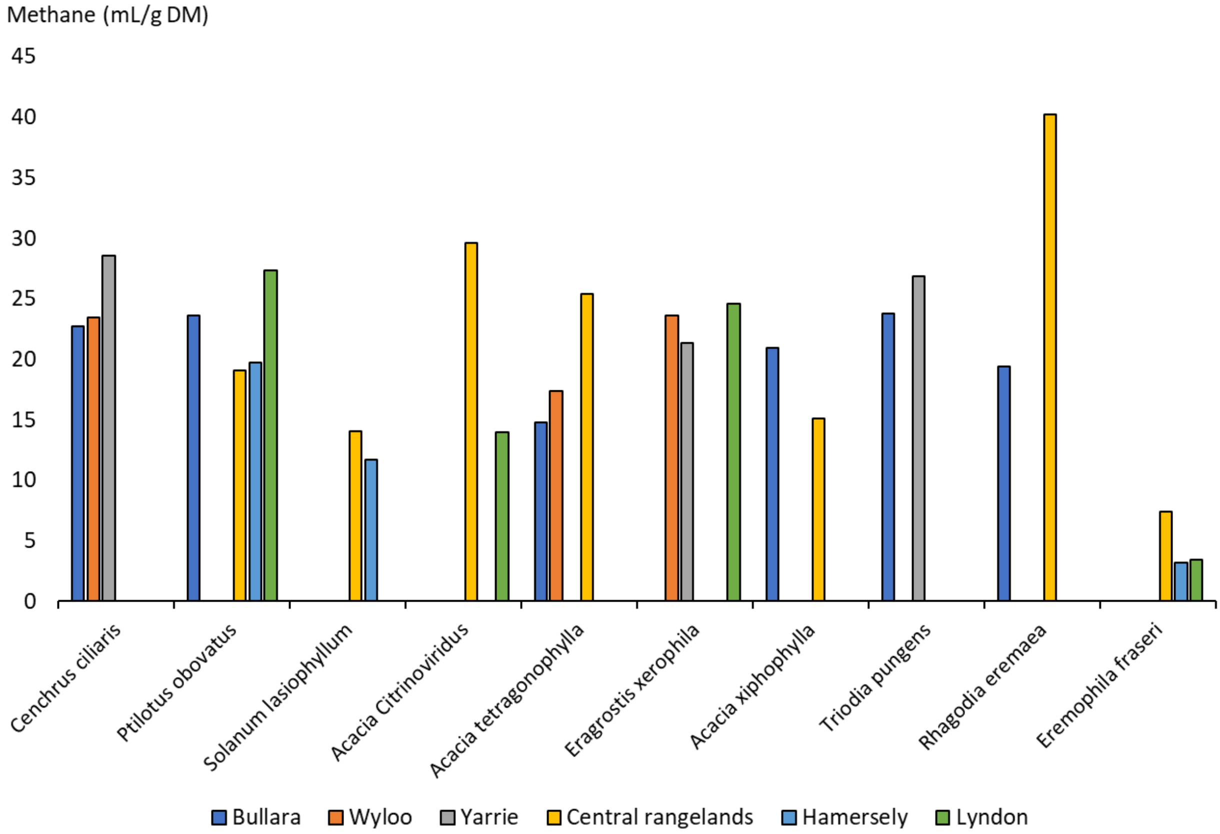
The average variation in methane produced within species between the stations was much higher (32%), although the tendency for each species to produce high, medium or low levels of methane was persistent. In particular, *E. fraseri* had a potent anti-methanogenic effect, but there was 57% variability between the Hamersley and Central Rangeland samples. This plant species is known to be abundant in plant secondary compounds (PSC), and other *Eremophila* species have also been linked to bioactivity in the rumen and anti-methanogenic properties. These differences may help identify which secondary compounds are responsible for the effect and assist in further selection of cultivars within the species.

Figure 2. Differences in gas (a) and methane (b) production from *in vitro* fermentation of same species collected at different stations

a



b



4.1.2 The effect of season on fermentation characteristics

Plant specimens from the wet season collection of 2021 produced significantly higher fermentation gas than the other seasons and this was reflected in the higher overall nutritive values. This aligns with our observation that many of the plants were in a vegetative growth stage while plants were mature and senescing in the other seasons. Interestingly, overall, there was no significant difference in the methane concentration of the fermentation gas between any of the seasons. Although methane concentration did differ between individual species, high, moderate and low methane species remained in the same methane category between each season (Table1.).

4.1.3 RUSITEC 3: Plant mixes for improved performance

There were three RUSITEC experiments in the project, culminating in RUSITEC 3. In RUSITEC 1, four plants that reduced methane formation in the *in vitro* batch fermentations were tested as the sole substrate. The plants reduced methane formation but reduced overall fermentation. In RUSITEC 2, the same plants were tested at a low dose (20% inclusion) with oaten chaff as the major substrate. A high potency in methane inhibition was observed. The objective of RUSITEC 3 was to design mixes of plant species to investigate if it is possible to offset the methane production from a common high methanogenic substrate oaten chaff, while improving fermentative and nutritive outcomes. We hypothesized that.

1. Grazing mix: A formulation designed on a common grass and herb species would improve fermentation (VFA) and acetate to propionate profile (A:P ratio) while providing a small methane reduction v control
2. Moderate methane mix: A formulation designed on common grass and a tree species

with moderate methane inhibition would maintain fermentation (VFA) while providing a moderate methane reduction v control

3. Methane mix: A formulation designed on two anti-methanogenic species would tend to decrease fermentation (VFA) while providing a high methane reduction v control
4. Grazing and methane mix: A formulation designed on all four rangeland species would improve fermentation (VFA) and A:P ratio while providing a high methane reduction v control

Hypothesis 1 was partially supported. The "**Grazing mix**" designed on a common grass and herb species did not improve fermentation (total gas yield and or yield of VFA) or the acetate to propionate ratio (A:P) ratio but did reduce methane formation by 16% versus the oaten chaff control (Fig. 3.). In Week 2 the grazing mix tended to increase gas production and lower A:P, although the differences were not significant. The acclimatization lag must be considered with all the treatments. This is a limitation with most *in vitro* and *in vivo* studies and highlights the need for longer-term studies.

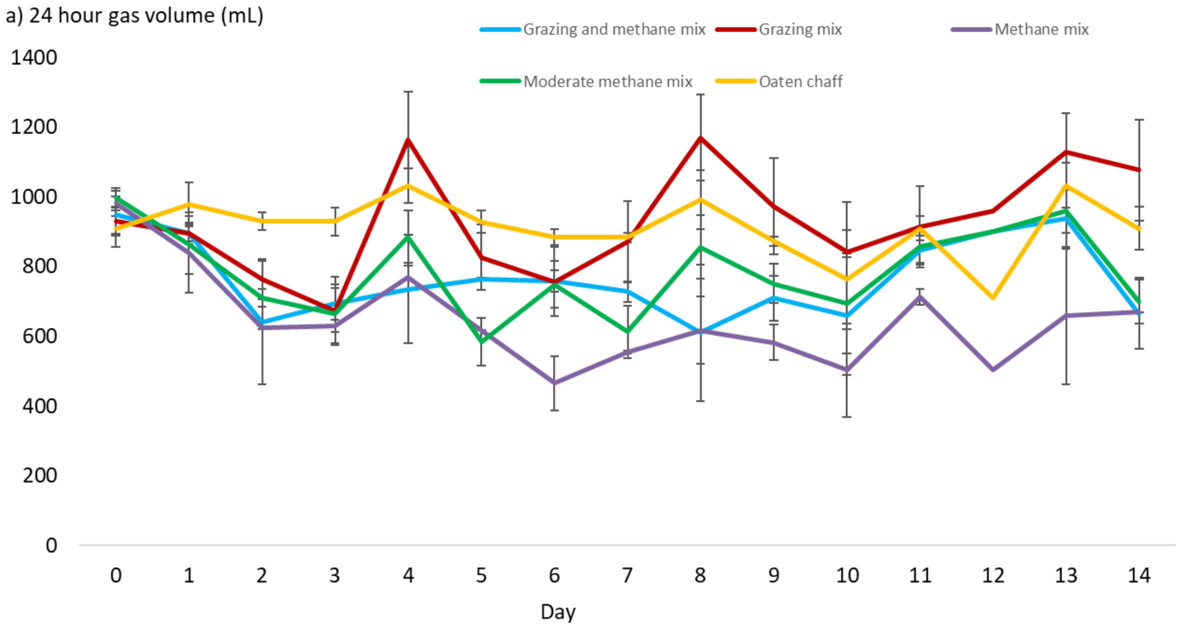
Hypothesis 2 was partially supported. The "**Moderate methane mix**" designed on common grass and a tree species reduced methane by an average of 30% over two weeks versus the control but with a moderate reduction of fermentation gases and VFA. The reduced gas production could, in part, be attributed to a reduction in the methane component of the gas mix but the energy that would have been conserved was not translated into increased total VFA or propionate production.

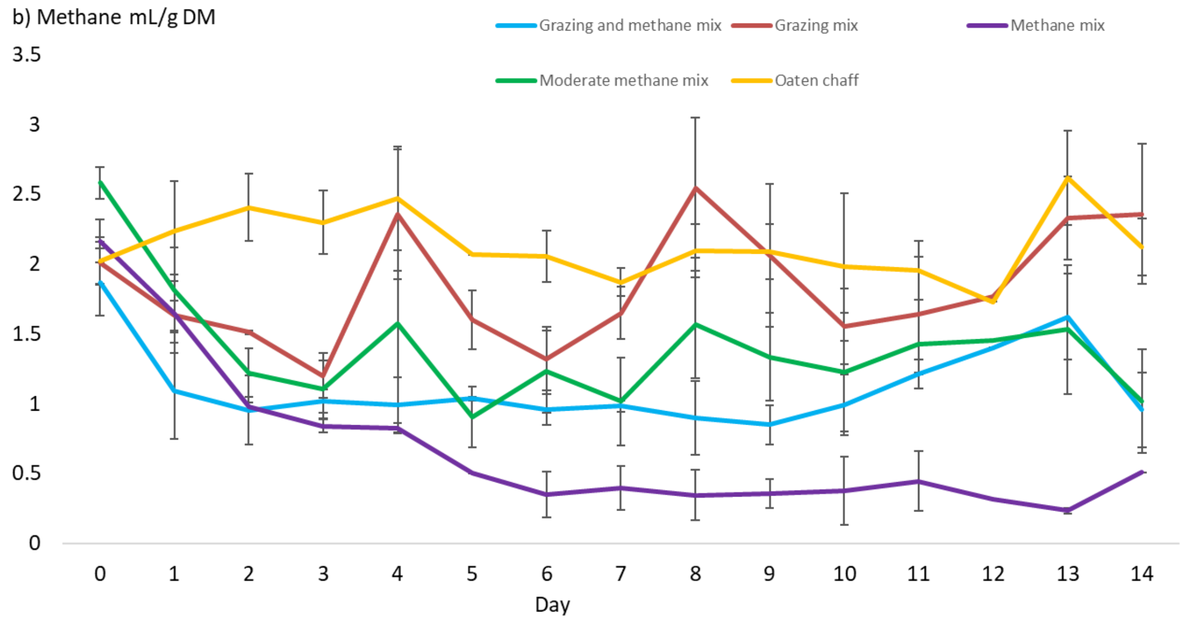
Hypothesis 3 was supported. The "**Methane mix**" combination of two anti-methanogenic plant species providing a high methane reduction compared with the control, but decreased fermentation end products. It is important to note that the anti-methanogenic effect was apparent when the base substrate of oaten chaff comprised 60% of the total substrate. Further, there was a 60% increase in VFA in the second week without a reduction in methane efficacy indicating a favorable acclimatization to the change in diet.

Hypothesis 4 was partially supported. The "**Grazing and methane mix**" designed on all four rangeland species provided a high (about 50%) methane reduction, improved A:P ratio and did not inhibit overall fermentation compared to the oaten chaff control. It is likely that in an environment where animals were fully acclimatized to the diet, fermentation end products would be higher than a pure oaten chaff diet because the grazing and methane mix had a better nutritional profile than the oaten chaff control.

Overall, we demonstrated that, in a laboratory environment, it is possible to formulate diets that mimic, at a superficial level, the complex diversity of plants on offer for rangeland cattle, using plants with varying methanogenic potential, fermentative and nutritive profiles to enhance methane inhibition and fermentation end products. Diets similar to the "**Grazing mix"** tested here have the potential to develop grazing strategies in the northern rangelands to move towards zero net carbon emissions while maintaining productivity.

Figure 3. Average daily (mean ± se) (a) total gas production (mL) (b) CH_4 concentration (mL/100 mL/ g of dry matter. Treatments added on Day 0.





4.1.4 Guidelines for practice changes and benefit realization

Animal performance is largely driven by diet. The value of feed for animal performance is a function of animal intake and the nutritive value of the feed. Many Australian plants contain secondary compounds that can modify rumen fermentation by inhibiting the growth of specific rumen microbes. Some of these compounds can improve the feed breakdown process and others are anti-nutritional. Some secondary compounds inhibit the process of methane formation, and this is a desirable trait. Not only does this result in less greenhouse gas emissions but less feed energy is lost during the break down of feed. Plant protein is essential for healthy microbial growth and for livestock maintenance and production. Plants with low protein levels in can limit animal production. The guidelines are headed by the top performers for fermentability (digestibility and production of volatile fatty acids) (Table. 2.), antimethanogenic activity (methane reduction) (Tbl.3.) and crude protein (Tbl. 4.) (8.1.2 Appendix II).

The benefit realization analysis was used to determine the likely adoption by producers of reseeding areas of their stations to desirable plant species identified in the project. The key issue that is raised is the relationship between feasibility (costs and associated extension and adoption opportunities), willingness to pay and the opportunities to monetize the outcomes of changing the landscape.

A post project CSIRO ADOPT analysis was undertaken based on the project objectives and outcomes. This provides some critical outcomes:

- Likely to adopt the technologies – 35% of producers within 14 years.
- The time to 50% peak adoption was noted as 6.2 years and it is likely that only 12% of producers would adopt this approach by 2028 raising to 31% by 2032.
- The most sensitive issue facing adoption was risk exposure. If producers can identify the co-benefits of the abatement strategy (e.g., gains in productivity, alternative revenue streams, environment co-benefits, the step-up adoption rate after 10 years increases to 52% of producers understanding the technology.
- If producers identified that the change in feedbase strategy was a risk to the business operations, the adoption rate after 10 years was identified as 15% of producers. These producers would be classically identified as 'early adopters' but may not be regional leaders.
- Accelerating the time to peak adoption was markedly affected by the level of advisory support and technical knowledge with advisors. If highly skilled advisors were used, the time to peak adoption was 1.3 years faster, but if there were few knowledge-based resources, adoption would slow by an average 1.2 years.

4.1.5 North South beef supply chains and opportunities for antimethanogenic plants

B.CCH.1012 and B.CCH.6540 addressed the potential of the Australian temperate feedbase to reduce methane production (either per unit of feed intake or per unit of animal production). The current project P.PSH.1262 using the same approaches to the projects focused on southern temperate systems but deploys them in a NW WA context. These projects benchmarked the variation between and within species of temperate and tropical, herbaceous forage species for antimethanogenic effects and identify variability in the provision of digestible nutrients at times of the year where they typically limit animal production. The work undertaken in B.CCH.1012 and 6540 identified a number of species (annuals) that were commercially available (e.g. Biserulla pelecinus, Medicago arabica, Ornithopus sativus, Trifolium subterraneum var. yanninicum; T.s. var. brachycalycinum & subterraneum that had an impact on methane production without impacting on VFA production. Biserrula was also identified as a plant that increased propionate production. Dorycnium hirsutum and Dorycnium rectum, Lotus corniculatus and Onobrychis viciifolia showed potential.

To capitalise on the potential of antimethanogenic plants (either perennial or annual), integration of the species into the WA beef supply chain at scale is determined by the availability of these species, the ability of the producer to establish either monocultures or diverse mixed swards, or integrated grazing systems (e.g. tree-shrub- forb-grass) interrow plantings. We have noted in this report and in P.PSH.1245 (Diet-ID) that cost-effective integration is driven by the these attributes of plants as well as the ability of the chosen species to survive for a number of years in production systems. At a rangeland scale, it is unlikely that a number of plant species (with antimethanogenic properties) would survive and become a species that was grazed preferentially (as noted by the diversity of plants that are grazed under rangeland conditions (P.PSH.1245). Therefore, if these plants are not integrated within the rangelands, establishment within backgrounding systems may be an opportunity that needs further evaluation. Recent whole supply chain emissions (methane production – Hill and Vercoe, unpublished data) has demonstrated that proportion of total greenhouse gas emissions ($KgCO_2e$) ascribed to animals growing under rangeland conditions, backgrounding and feedlot were 25-30%, 12-20% and 50-60% respectively. Integration of low methane producing plants within a backgrounding system changes the trajectory of emissions for the domestic (feedlot finished supply chain) and potentially have downward pressure on emissions of animals that would enter the live export supply chain (under those conditions backgrounding may be >25% of total GHG emissions per head). Perennial species that are being tested in small amounts in the backgrounding region that have overlap with plant species we've screened for the northern rangeland systems are Gatton Panic and Rhodes grasses as well as Rhagodia and some saltbush shrub species (most recently Anameka). We believe that there is scope for Cullen, Maireana, Atriplex, some species of Eremophila, and possibly Biserrula plant species the overlap between northern and southern systems in the backgrounding region of the supply chain (e.g. Mingenow-Irwin, West Midland districts).

5. Conclusion

The CN30 project has been successful in quantifying the diversity in anti-methanogenic and productivity properties of naturally occurring plant species that make up the feedbase in northern WA beef production. Selection and collection of target species was informed by the literature, pastoralist knowledge and botanical expertise. However, future work should focus on diet identification technologies to provide more robust information on the actual and dynamic composition of the diet of rangeland cattle.

The in vitro analysis of the plant collection identified species with potent methane inhibition and with potential benefits for animal production and the effects were shown to persist over time within the RUSITEC experiments. The effects were also evident when plant material was collected from a range of locations (multiple stations) and when collected over two seasons and multiple years (Hamersley station). We demonstrated, in the RUSITEC, the potential of diets containing a mixture of key species to achieve methane reduction and while maintaining fermentation. However, the effects on methane reduction and benefits to animal production need to be validated in-field. In-field technologies for measuring methane and for feedbase identification will help to develop the rangeland beef industry.

Improving the existing feedbase by sowing key plant species into regenerative zones will increase ground cover, improve animal productivity and increase biodiversity. Currently, efforts to increase the establishment of key plant species on rangeland stations are prohibited by low return on investment due to high seed costs and low stocking rates because of the semi-arid environment. Subsequently, the CSIRO adoption modelling forecasts a low peak adoption level (35%) and a slow rate to peak adoption (14 years). Many of the species identified in this report as conferring antimethanogenic properties come from the central and northern rangelands of WA. This project did not address the opportunities of establishing these plants across extant areas. In previous work, ENRICH – 2 did evaluate how some of these species could be used in pastures and modelling methane emissions from livestock grazing those types of pastures. This work is important in developing the next steps for the current surveys. The development of secondary market incentives such as carbon and natural capital credits may make it viable to seed rangeland areas. Presently, grazing management is the best practice for feedbase regeneration with the aim of preserving the existing feedbase and seedbank. Rangeland condition can be enhanced with the development of technologies including virtual fencing, diet identification and improved backgrounding practices.

5.1 Key findings

- Plants were identifying that reduced methane and promoted favourable fermentation for improved animal performance.
- Around 100 species were tested and this is a subset of over 12,000 species that are present in WA. Using Diet identification techniques would better allow the targeting of key species in the diet.
- There is a need for testing *in vivo* (animal studies) and to validate these studies under real time grazing conditions.
- Adoption of practices to introduce key species to their stations is risk prohibitive due to low returns from high seeding costs and low stocking rates in arid and semi-arid areas.

5.2 Benefits to industry

This work is valuable for the direct abatement of methane emissions of northern cattle through targeted grazing management of key plant species using technology such as virtual fencing. A large diversity in plant species was identified with anti-methanogenic and desirable nutritive characteristics. It is critical to continue adding to the knowledge of the feed base that comprises the diet of rangeland cattle.

The benefits to the wider red meat industry include consistency of production by focussing on the management of key species across the supply chain. The potential for methane abatement is high from the array of bioactive plant species identified. The Western Australia beef industry has the opportunity of addressing the increasing global demand for red meat while becoming a carbon neutral value chain.

6. Future research and recommendations

Future work must focus on continued development of the database library. The more feed base information available to producers the greater the grazing management opportunities and supply chain stabilisation. Presently a major barrier to feed base development is the identification of what the animal consumes under free-ranging grazing scenario. Without such data, it is difficult to determine the abatement across a large herd scale. This is why this work also underpins P.PSH.1245.

Projects that focus on technologies to identify key nutritive and anti-methanogenic species in the diet will allow rapid improvement of the feed base.

Another key challenge will be the application of potent anti-methanogenic plant species that are not part of the diet. It is possible that plants that are high secondary compounds that reduce methane formation in the gut also have poor palatability. For example, Eremophila species are often described as low grazing preference but were often observed to be potent for methane reduction. The potential application of these species may be for compound extraction for use as feed additives.

Practical application of the data generated from the project should focus on three main areas. First, the application of key species identified in the guidelines to individual scenarios. Second, developing strategies to implement species preservation and regeneration for profitability. BEEFLINKS project such as Virtual Fencing offer a high potential for the practical grazing management of desirable species.

Development and adoption activities would focus on the implementation of surveys undertaken on pastoral and rangeland stations to identify species that were preferentially selected as part of the animal's ration. These surveys could be undertaken using eDNA and fDNA technologies developed in P.PSH.1245. Adoption of technologies to re-establish anti-methanogenic species in rangelands are probably going to be low reflecting the difficulties in deployment of technologies for seeding.

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8. Appendix

8.1.1 Appendix I. Top performers for fermentability, antimethanogenic activity and crude protein

NUTRITIVE AND FERMENTABILITY PROFILES

Animal performance is largely driven by diet. The value of feed for animal performance is a function of animal intake and the nutritive value of the feed.

The nutritive value of the feed represents the capacity of the various components of the food to allow the animal to perform its regular functions, for instance to move muscles, to metabolise nutrients, to produce heat, to be pregnant, to grow and to lactate. Energy intake is often the most limiting component of rangeland diets and so it makes sense that we improve our knowledge on the capacity of rangeland plant species to provide adequate energy to cattle.

The energy value is determined by chemical tests of the feed and includes fibre levels such as neutral detergent fibre (NDF) and acid detergent fibre (ADF) to produce a digestibility and, by calculation, the metabolizable energy estimation. However, the relationship between fibre content and digestibility is well understood for conventional pastures but not for rangeland plant species. Gas and volatile fatty acid production from fermentation is a better indication of the nutritive value of rangeland plant species.

We tested each plant species using a laboratory technique based on rumen fluid from a flock of donor animals. The feed was incubated for 24 hours in a stabilised fermentation mixture containing the rumen fluid. The fermentation was in sealed flasks that were warmed and gently shaken. We then measured the end products of fermentation including gas production and volatile fatty acids. High gas volumes represent highly fermentable/digestible feed and, in general, are associated with good animal performance. Volatile fatty acids (VFA) also relate to fermentability of the feed but is a more direct indication of the feed value. VFA are like fuel for the animal and, in general, the more that are produced from feed the more fuel the animal has at its disposal. Volatile fatty acids are the main source of energy for the ruminant animal. High levels of VFA from fermented plants are an indication that the feed is of high value.

TABLE 2. Top performers for fermentability (digestibility) and total production of total volatile fatty acids by rumen microbes

Scientific name	Common name	Life form	Fermentability (Gas mL/g of dry matter)	Volatile fatty acids (mM)
	Average all species		320	79
	Oaten chaff (control)		320	73
1 *Swainsona formosa*	Sturt desert pea	Short-lived herb	380	113
2 **Psydrax latifolia*	Wild Lemon, bush plum	Small tree	380	100
3 *Ipomoea muelleri*	Poison morning Glory	Climbing perennial herb	370	111
4 *Dodonaea lobulata*	Bead Hopbush	Spreading shrub	370	98
5 *Portulaca oleracea*	Purslane	Succulent	370	99
6 *Eremophila maculata subsp. Brevifola*	Fuschia bush	Shrub	340	106
7 *Ptilotus auriculifolius*	Ear-leaved Mulla Mulla	Annual herb	360	100
8 *Cenchrus setiger*	Birdwood Grass	Grass	340	70
9 *Eragrotis eriopoda*	Wollybutt grass	Grass	340	77
10 *Astrebla elemoides*	Hoop Mitchell Grass	Grass	310	86
11 *Acacia xiphophylla*	Snakewood	Tree	300	92

*Previously called *Canthium latifolium*

ANTIMETHANOGENIC PROPERTIES

Many Australian plants contain secondary compounds that can modify rumen fermentation by inhibiting the growth of specific rumen microbes. Some of these compounds can improve the feed breakdown process and others are anti-nutritional. Some secondary compounds inhibit the process of methane formation and this is a desirable trait. Not only does this result in less greenhouse gas emissions but less feed energy is lost during the break down of feed. The saved energy can potentially be used by the animal for production. When methane formation is reduced, often the level of propionic acid (a type of volatile fatty acid) is increased and can lead to better animal production. The increase in propionic acid is often at the expense of acetic acid resulting in a lower acetate to propionate ratio (A:P), which is a good trait. Some secondary compounds inhibit ammonia producing bacteria and this is a favourable trait because, in diets with adequate crude protein, low ammonia production can be beneficial for animal production and less nitrogen is excreted into the environment.

TABLE 3. Top performers for bioactivity on rumen microbes

Scientific name	Common name	Life form	Methane (% of total gas fermented)	A:P	Ammonia (mg/g crude protein)
	Average for all species		19.6	3.2	81
	Oaten chaff (control)		15.0	2.9	43
1 *Eremophila fraseri*	Turpentine bush, Burra	Viscid shrub	2.6	1.9	9
2 *Eremophila glabra*	Emu Bush	Spreading shrub	4.3	1.7	61
3 *Senna artemisioides subsp. oligophylla*	Senna	Spreading shrub	5.6	2.3	-
4 *Eremophila maculata subsp. Brevifola*	Fuschia bush	Diffuse shrub	7.1	2.0	59
5 *Eremophila cuneifolia*	Compact eremophila	Spreading viscid shrub	8.5	2.2	8
6 *Ptilotus exaltatus*	Pink/Tall Mulla Mulla	Erect Annual Herb	10.8	4.0	114
7 *Solanum lasiophyllum*	Flannel Bush	Erect shrub	11.1	3.2	122
8 *Scaevola spinescens*	Currant Bush	Shrub	11.1	2.8	5
9 *Acacia colei*	Acacia	Tree	11.1	3.0	31
10 *Themeda sp. Hamersley*	Kangaroo grass	Grass	16.1	3.5	77

CRUDE PROTEIN

Ruminants have the ability to synthesise protein from non-protein nitrogen (NPN) sources. Most of the crude protein that ruminants ingest is broken down by the rumen microbes and resynthesised as microbial protein that is stored in the microbes themselves. The microbes are continually flushed out of the rumen and are digested further down the digestive tract. This is a major source of protein for the animal. Plant protein is essential for healthy microbial growth and for livestock maintenance and production. Plants with low protein levels in can limit animal production. The level of crude protein required for growing weaners is around 15 to 18% of the feed.

TABLE 4. Top species for crude protein content

Scientific name	Common name	Life form	Crude protein %
	Average for all species		11
	Oaten chaff (control)		5
1 *Swainsona formosa*	Sturt's Desert Pea	Prostrate herb	22
2 *Maireana sedifolia*	Blue bush	Compact, divaricately branched shrub	22
3 *Ptilotus exaltatus*	Pink/Tall Mulla Mulla Mulla Mulla	Erect Annual Herb	17
4 *Vachellia farnesiana*	False Mimosa	Thicket forming tree	17
5 *Ptilotus auriculifolius*	Ear-leaved mulla mulla	Annual herb	15
6 *Eremophila forrestii*	Wilcox Shrub	Much-branched shrub	15
7 *Rhagodia eremaea*	Rhagodia	Shrub	15
8 *Acacia craspedocarpa*	Hop mulga	Broad-leaved shrub or tree	15
9 *Portulaca oleracea*	Purslane	Succulent	14
10 *Acacia acuminata*	Jam	Tree	14