Interactive Antimicrobial Profiles of *Astragalus membranaceus* (Fisch.) Bunge Extracts and Conventional Antibiotics against Pathogenic and Non-pathogenic Gastrointestinal Bacteria

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ABSTRACT

**Background:** The aim of this project was to investigate the efficacy of *Astragalus membranaceus* (Astragalus) extracts, alone and in combination with conventional antibiotics, against diarrhoea- and dysentery-causing pathogens, as well as against non-pathogenic gastrointestinal bacterial strains. The study sought to validate the chemotherapeutic potential of a traditional Chinese medicinal plant and to identify combinational therapies with increased efficacy compared to either the extracts or conventional antibiotics alone. **Methods:** Astragalus root powder was extracted with solvents of varying polarity and screened for inhibition of bacterial growth. Susceptibility was assessed by disc diffusion techniques, whilst the minimum inhibitory concentrations (MICs) were quantified by liquid dilution assays. To screen for combinatorial effects, the Astragalus root extracts were combined with a range of conventional antibiotics and tested against each bacterial strain using liquid dilution assays. **Results:** Aqueous Astragalus root extracts did not significantly inhibit the growth of the non-pathogenic or beneficial gut microflora bacteria *E. cloacae, E. coli or E. faecalis*, but possessed mild inhibitory activity against pathogenic *A. faecalis, A. hydrophila, B. cereus, S. newport* and *S. sonnei* bacteria. Combinations of the Astragalus extracts and conventional antibiotics generally produced additive or indifferent interactions, indicating that they are safe to use concomitantly without compromising the efficacy of either component. Two cases of antagonistic combinations were detected against *B. cereus* and *S. sonnei*. **Conclusion:** Mild inhibition of 5 pathogenic bacteria occurred with aqueous Astragalus extracts, with a number of additive and antagonistic interactions arising when tested in combination with conventional antibiotics. Astragalus may be used safely in the presence of normal gut bacteria and in most combinations with conventional antibiotics. **Key words:** Traditional Chinese Medicine (TCM), Fabaceae, Astragalus, DisC diffusion, Liquid dilution assays, Combinational therapies, Diarrhea, Synergy.

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INTRODUCTION

The World Health Organization (WHO) has reported that more than half a million children under the age of 5 die each year from diarrhoeal disease, equating to over 1400 deaths per day. Diarrhoea remains a leading killer of children, accounting for 8% of all death among children of this age group. Exacerbating the problem are bacteria that have developed resistance to conventional antibiotics, rendering these medicines ineffective against diarrhoea-causing pathogens. As such, an urgent need has arisen for the development of new treatment options to combat these illnesses, either through novel drug molecules or by utilizing new therapy regimens that enable, or re-purpose, previously effective antibiotics that have lost their potency due to the emergence of highly resistant infections. Many plants used in traditional medicinal systems are effective in the treatment of diarrhoea. Traditional Chinese Medicine (TCM) has been used for thousands of years as a method for treating a variety of different ailments and is a prominent feature of Chinese history and culture. Traditional healing practices have become increasingly accepted by people in many regions of the world in recent years, with more researchers now exploring the scientific merit of TCM. *Astragalus membranaceus* (Fisch.) Bunge or Astragalus; (also known as Huangqi - 蒼芪) is one of the most widely used Chinese medicinal plants (Figure 1a) and is mainly grown in the northern regions of China as well as in Mongolia and Siberia. In recent years, the chemical composition and the pharmacological activity of Astragalus have been studied extensively (Figure 1b-e). Chemical analysis of the plant revealed that Astragalus is predominantly composed of polysaccharides, triterpenes and flavonoids. Pharmacological evidence suggests that Astragalus possesses therapeutic benefits for the immune system and for liver and kidney protection, whilst also having anti-tumorigenic, antiviral, anti-hypertensive and antiabetic properties. Astragalus has also been incorporated into conventional medicines to treat chronic kidney disease, diabetes, breast cancer, neurodegenerative and coronary diseases. The mechanism of action of Astragalus plant extracts has recently been the focus of considerable investigation. For example, the inhibitory effects of the plant on peritoneal fibrosis may involve both MCP-1 and TGF-β/Smad pathways. Additionally, extracts from Astragalus inhibit breast cancer cells proliferation via PI3K/AKT/mTOR signaling pathway. Astragalus can also regulate INOS activity of macrophages in different states in vitro by Astragalus polysaccharides. However, studies on the antibacterial properties of Astragalus are lacking. Since the herb is predominantly ingested, thereby reaching sections of the gastrointestinal (GI) tract where both normal gut flora and disease-causing bacteria co-exist, there is a need to investigate the effects of Astragalus on gastrointestinal bacterial strains. Inhibition of the growth of these strains may be beneficial in treating pathogenic disease. However, an understanding of the antibacterial effects of Astragalus plant extracts on normal gut flora is also important as Astragalus extracts are ingested by members of the community for a wide spectrum of ailments unrelated to bacterial infection. Bacterial strains which are non-pathogenic and...
normal components of the gut microbiome were therefore also included in the current study. Adherents of complementary and alternative medicine often use both traditional and allopathic medications concurrently without any regard to the interactions between the medicines and the possible side effects which may occur. Potential combination interactions may pose serious risks to patient safety and a greater understanding of these effects is required. Notably, it has been estimated that up to approximately 70% of patients in Western countries use herbal drugs concurrently with prescription drugs. Furthermore, it is likely that the use of herbal therapies in combination with over-the-counter medications is substantially higher, with many patients combining these two medicinal systems believing that the combination would provide an enhanced effect. Often this self-prescribing occurs without the knowledge of their physician and there have been many instances where severe reactions have resulted. Much more work is required to test the effects of allopathic and complementary drug combinations on both the safety and efficacy of the combinations.

In this report, we tested Astragalus root powder extracted with solvents of varying polarity against diarrhoea-causing Alcaligenes faecalis, Bacillus cereus, Salmonella newport, Aeromonas hydrophila, Escherichia coli and Shigella sonnei, all of which are known bacterial triggers of GI diseases. A. faecalis may cause systemic infections and symtpomatic peritonitis which can be fatal if untreated. S. newport causes an estimated 1.2 million illnesses, 23,000 hospitalizations and 450 deaths annually and Salmonella is a serious threat to public health. B. cereus produces mucin in the gut which induces the onset of pathogenesis. S. sonnei is a major public health concern worldwide, especially in developing countries, with acute intestinal infections requiring a minimum infective dose as low as 10–100 bacterial cells, while A. hydrophila can induce intestinal mucosal barrier function damage and inflammation. The genus Escherichia consists of facultative anaerobic Gram-negative bacilli that belong to the family Enterobacteriaceae and although most E. coli strains live harmlessly in the colon and seldom cause disease in healthy individuals, a number of pathogenic strains can cause intestinal and extra-intestinal diseases, both in healthy and immunocompromised individuals. In contrast, Enterococcus faecalis and Enterobacter cloacae are harmless bacterial residents of the gastrointestinal microbiome. They have been included in this study to determine whether Astragalus is capable of inhibiting these non-pathogenic strains, which could ultimately alter the gut microbiome. The efficacy of Astragalus extracts, alone and in combination with conventional antibiotics, against five pathogens that trigger diarrhea and against two non-pathogenic GI bacteria, were assessed.

MATERIALS AND METHODS

Collection of plant samples

The Astragalus root powder used in this study was sourced from verified plants in China by Noodles Emporium (Australia) and supplied as a dried, ground powder. A voucher sample (NSC2017wscic) has been stored at the School of Environment and Science, Griffith University, Australia.

Preparation of extracts

Individual 1.5 g quantities of the material were weighed into separate tubes and deionised water, methanol, ethyl acetate, hexane or chloroform were added to 50 mL. All organic solvents were obtained from Ajax, Australia and were AR grade. The ground plant materials were individually extracted in each solvent for 24 h at 41°C with gentle shaking. The extracts were subsequently filtered through filter paper (Whatman No. 54) under vacuum and dried at 42°C, with the resultant extracts weighed and resuspended in 10 mL deionised water (containing 1 % DMSO). The suspensions were briefly sonicated (3 x 20 s pulse cycles, at 2 kHz), sterilised by filtration through a 0.2μm membrane and stored at 4°C until required for further analysis.

Qualitative phytochemical studies

Phytochemical analyses of the Astragalus root extracts for the presence of saponins, phenolic compounds, flavonoids, phytoesters, triterpenoids, cardiac glycosides, anthraquinones, tannins and alkaloids were conducted by previously described assays. Antibiotics

Penicillin-G (potency of 1440-1680 μg/mg), chloramphenicol (≥98 % purity by HPLC), erythromycin (potency ≥850 μg/mg), ciprofloxacin (≥98 % purity by HPLC) and tetracycline (≥95 % purity by HPLC) were purchased from Sigma-Aldrich (Australia) and were used as controls for the microplate liquid dilution assay. All antibiotics were prepared in sterile deionised water at stock concentrations of 0.01 mg/mL and stored at 4°C until use.

Bacterial cultures

Reference strains of A. faecalis, B. cereus, A. hydrophila, S. sonnei, E. faecalis, E. coli and E. cloacae were purchased from the American Type Culture Collection (USA). The S. newport clinical isolate strain was obtained from the School of Environment and Science teaching laboratory. All bacteria were cultured in nutrient broth (Oxoid Ltd., Australia). Streaked nutrient agar (Oxoid Ltd., Australia) plates were tested in parallel to ensure the purity of all bacterial cultures and for sub-culturing.

Disc diffusion assays on agar

Antibacterial activity screening of the Astragalus root extracts on solid agar was assessed using a modified disc diffusion assay method. Briefly, single colonies of the test bacteria isolated from streaked agar plates were grown at 37°C in 40 mL of fresh nutrient broth media until they reached a count of approximately 10⁶ cells/mL. The visual turbidity of each culture was adjusted in order to prepare 0.5 McFarland standards. A volume of 100 μL of the individual microbial suspensions were spread onto nutrient agar plates. Extracts (10 μL) were infuson
Liquid extraction yields and phytochemical screening

Astragalus root extractions (1.5 g material) using various solvents yielded dried plant extracts ranging from 54 mg to 245 mg (Table 1). Aqueous,

<table>
<thead>
<tr>
<th>Extract Type</th>
<th>Mass of Extract (mg)</th>
<th>Resuspended Extract (mg/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanol</td>
<td>218</td>
<td>21.8</td>
</tr>
<tr>
<td>Water</td>
<td>245</td>
<td>24.5</td>
</tr>
<tr>
<td>Ethyl Acetate</td>
<td>54</td>
<td>5.4</td>
</tr>
<tr>
<td>Chloroform</td>
<td>187</td>
<td>18.7</td>
</tr>
<tr>
<td>Hexane</td>
<td>77</td>
<td>7.7</td>
</tr>
</tbody>
</table>

+++ indicates a large response; ++ indicates a moderate response; + indicates a minor response; - indicates no response in the assay.

### RESULTS

#### Liquid extraction yields and phytochemical screening

<table>
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<tr>
<th>Extract Type</th>
<th>Mass of Extract (mg)</th>
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<td>77</td>
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</tbody>
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The mass of dried extracted material, concentration after resuspension in deionised water and qualitative phytochemical screenings for the Astragalus root extracts are shown in Table 1. The FIC values for each component (a and b) were calculated using the following equations where a represents the plant extract sample and b represents the conventional antibiotic:

\[
FIC(a) = \left( \frac{MIC_{a \text{ in combination with } b}}{MIC_{a \text{ independently}}} \right)
\]

\[
FIC(b) = \left( \frac{MIC_{b \text{ in combination with } a}}{MIC_{b \text{ independently}}} \right)
\]

The ΣFIC was then calculated using the formula ΣFIC = FIC(a) + FIC(b). The interactions were classified as synergistic (ΣFIC ≤ 0.5), additive (ΣFIC > 0.5-1.0), indifferent (ΣFIC > 1.0-4.0) or antagonistic (ΣFIC > 4.0). 37-38

**Artemia nauplii toxicity screening**

An aqueous preparation (4 mg/mL) of potassium dichromate (K₂Cr₂O₇) (AR grade, Chem-Supply, Australia) was serially diluted in artificial seawater for use as a reference toxin. Toxicities of the Astragalus root extracts, the reference toxin and the conventional antibiotics were assessed using a modified Artemia franciscana nauplii lethality assay. 40-41

The LC₅₀ with 95% confidence limits for each treatment was calculated using probit analysis.

**Statistical analysis**

Data are expressed as the mean ± SEM of at least three independent experiments, each with internal triplicates (n=9). One way ANOVA was used to calculate statistical significance between control and treated groups with a P value < 0.01 considered as statistically significant.
methanolic and chloroform extracts provided significantly greater yields of extracted material relative to the hexane and ethyl acetate, which gave low to moderate yields. The dried extracts were resuspended in 10 mL of deionised water (containing 1% DMSO), resulting in the concentrations presented in Table 1. Qualitative phytochemical studies (Table 1) showed that methanol and water extracted the widest range and greatest relative abundance of phytochemicals. Both showed high levels of phenolics (both water soluble and insoluble phenolics) and flavonoids, as well as high to moderate levels of tannins and saponins. The ethyl acetate and chloroform extract also had low levels of phenolics and flavonoids. Moderate flavonoid levels were also detected in the ethyl acetate extract. No phytochemical classes were detected in the hexane extract.

Quantification of minimum inhibitory concentration (MIC)
Interestingly, none of the Astragalus extracts inhibited bacterial growth of any of the strains in the disc diffusion studies, indicating that the extracts are ineffective in the solid agar test model. However, zones of inhibitions were observed for the positive control antibiotics with varying efficacies, demonstrating that the assay was functioning correctly (Table 2). The antimicrobial efficacies of the Astragalus extracts were further assessed by determining the MIC values using liquid dilution assays. Only the aqueous extract showed inhibitory properties, with MIC values of 8167 µg/ml against A. faecalis, A. hydrophila, B. cereus, S. newport and S. sonnei (Table 3). Whilst inhibition was noted, these MIC values indicate only low antibacterial activity. None of the extracts showed activity towards E. cloacae, E. coli, or E. faecalis. MIC values for the positive control antibiotics against all strains in liquid dilution assays are shown in Table 3.

**Table 2:** Zones of inhibition for the positive control antibiotics (1 µg per disc) used in this study, as determined using agar disc diffusion assays. Zones include the diameter of disc (6 mm).

<table>
<thead>
<tr>
<th>Antibacterial MIC (µg/mL)</th>
<th>A. faecalis</th>
<th>A. hydrophila</th>
<th>B. cereus</th>
<th>E. cloacae</th>
<th>E. coli</th>
<th>E. faecalis</th>
<th>S. newport</th>
<th>S. sonnei</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXT</td>
<td>8167</td>
<td>8167</td>
<td>8167</td>
<td>-</td>
<td>-</td>
<td>8167</td>
<td>8167</td>
<td>-</td>
</tr>
<tr>
<td>Pen</td>
<td>0.11</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.11</td>
<td>0.037</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ery</td>
<td>0.33</td>
<td>-</td>
<td>-</td>
<td>0.037</td>
<td>0.11</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Tet</td>
<td>0.11</td>
<td>0.012</td>
<td>0.11</td>
<td>0.037</td>
<td>0.012</td>
<td>0.03</td>
<td>0.012</td>
<td>0.012</td>
</tr>
<tr>
<td>Chl</td>
<td>-</td>
<td>0.037</td>
<td>-</td>
<td>0.33</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.11</td>
</tr>
<tr>
<td>Cip</td>
<td>0.012</td>
<td>0.00015</td>
<td>0.037</td>
<td>0.00015</td>
<td>0.037</td>
<td>0.012</td>
<td>0.00015</td>
<td>0.012</td>
</tr>
</tbody>
</table>

EXT = aqueous Astragalus extract; Ery = erythromycin; Tet = tetracycline; Chl = chloramphenicol; Cip = ciprofloxacin; (-) indicates that no inhibition was detected.

**Table 3:** MIC values for aqueous Astragalus extract and the positive control antibiotics used in this study, as determined using liquid dilution assays.

**Table 4:** ΣFIC values of Astragalus aqueous extracts in combination with conventional antibiotics against the bacterial strains in this study that were found to be inhibited by the extract.

<table>
<thead>
<tr>
<th>Bacterial Strain</th>
<th>Pen</th>
<th>Ery</th>
<th>Tet</th>
<th>Chl</th>
<th>Cip</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. faecalis</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>ND</td>
<td>0.53</td>
</tr>
<tr>
<td>A. hydrophila</td>
<td>ND</td>
<td>ND</td>
<td>0.52</td>
<td>0.52</td>
<td>1.0</td>
</tr>
<tr>
<td>B. cereus</td>
<td>ND</td>
<td>9.12</td>
<td>1.59</td>
<td>1.0</td>
<td>1.44</td>
</tr>
<tr>
<td>S. newport</td>
<td>CND</td>
<td>ND</td>
<td>CND</td>
<td>ND</td>
<td>CND</td>
</tr>
<tr>
<td>S. sonnei</td>
<td>ND</td>
<td>ND</td>
<td>14.25</td>
<td>2.0</td>
<td>BND</td>
</tr>
</tbody>
</table>

Pen = penicillin; Ery = erythromycin; Tet = tetracycline; Chl = chloramphenicol; Cip = ciprofloxacin. ND = ΣFIC could not be determined as the antibiotic was not inhibitory at any concentration tested; CND = ΣFIC could not be determined as the combination was not inhibitory, while the antibiotic alone was inhibitory; BND = ΣFIC could not be determined as either the combination, or the antibiotic alone, were inhibitory at all concentrations tested. Additive (>0.5 to ≤1.0); Indifferent (>1.0 to ≤4.0); Antagonistic (>4.0).
DISCUSSION

Astragalus has been used in TCM for a wide array of therapeutic applications. However, TCM preparations often contain a mixture of different plant materials and thus analysis of the individual components can prove difficult. Therefore, it is important to be able to study a single plant species. In the present study, we acquired a pure preparation of the Astragalus root powder which enabled us to analyse it in isolation. Studies on the antibacterial properties of Astragalus are lacking. Therefore, one aim of this project was to investigate the efficacy of Astragalus (alone and in combination with conventional antibiotics) against pathogens which cause diarrhoea. Whilst we did detect some antibacterial activity in this study, most bacterial species examined were refractory to inhibition by the extracts. However, activity was observed for the aqueous Astragalus extract towards A. faecalis, A. hydrophila, B. cereus, S. Newport and S. sonnei, which are known triggers of gastrointestinal diseases. This suggests that Astragalus contains components that could be used to treat illnesses that feature these disease-causing bacteria, despite the fact that the bacteriostatic/cidal effects are relatively mild. To our knowledge, this represents that first evidence that Astragalus possesses bacterial growth inhibitory properties, especially against these specific strains. Importantly, none of the plant extracts affected the growth of the normal gut flora strains tested in this study (E. cloacae, E. coli or E. faecalis). This indicates that Astragalus treatment may be used safely without inducing detrimental shifts in the gastrointestinal microbiome which may allow harmful/pathogenic bacteria to flourish.

The combinational studies reported in this manuscript screened the Astragalus extracts for interactions with the conventional antibiotics. These studies are not only important to identify possible antimicrobial alternatives to overcome bacterial antibiotic resistance; they may also provide valuable information for clinical use of these therapies, where herbal therapy-conventional antibiotic interactions may occur. Many people use herbal therapies and conventional antibiotics concurrently, without any understanding of the interactions that may occur between the different medicines. Natural products may have severe interactions in combination with conventional medicines, even when either component is safe when used alone. Also of concern, the efficacy of a therapy may be affected in combination with other medicines. Whilst, some combinations may have increased potency, other combinations may antagonize each other's effects, thereby decreasing the efficacy of the therapy. It is important to identify such combinations so that they are avoided.

Several additive combinational interactions were noted. In particular, the water extract potentiated the activity of chloramphenicol against B. cereus and of either tetracycline or chloramphenicol against A. hydrophila. That extract also potentiated the activity of penicillin, erythromycin, tetracycline and ciprofloxacin against A. faecalis. As such, these combinations would be beneficial against diarrhea and dysentery, as they have greater efficacy than that of either component alone. Of the remaining combinations, the majority were either non-interactive, or were unable to be determined as at least one of the components in the combination showed no inhibition of bacterial growth when tested alone. Therefore, whilst using these combinations would have no additional therapeutic benefit, the components would not impede the activity of the other component. Notably, two combinations produced an antagonistic effect against B. cereus (extract with erythromycin) and S. sonnei (extract with tetracycline). These specific combinations should be avoided in the treatment of diarrhoea and any other diseases caused by these bacteria. The mechanisms of action regarding additive or antagonistic effects of the combinations against bacterial growth were not examined in this study. However, they may involve the alteration of specific cellular components by the plant extract to facilitate changes in the bacterial growth properties. Further investigations are necessary in order to more definitively identify the mechanism(s) involved.

Whilst a detailed investigation of the phytochemistry of the Astragalus extracts was beyond the scope of this study, the qualitative phytochemical studies highlighted several phytochemical classes that may contribute to the bacterial growth inhibitory activity and to the combinational effects noted in this study. The aqueous extracts had relatively high abundances in polyphenolics, saponins, flavonoids and tanins. The antibacterial activities are well known for a wide variety of flavonoids.

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Figure 2: The lethality of the Astragalus extracts (2000 μg/mL) and the potassium dichromate (1000 μg/mL) and seawater controls towards Artemia nauplii after 24 hours exposure. M = methanolic extract; W = aqueous extract; E = ethyl acetate extract; C = chloroform extract; H = hexane extract; NC = negative (seawater) control; PC = potassium dichromate control (1000 μg/mL). Results are expressed as mean % mortality ± SEM. * indicates results that are significantly different to the untreated control (p<0.01).
inhibit bacterial growth via a variety of mechanisms, including their ability to complex with extracellular and soluble proteins and as well as bacterial cell walls. Similarly, multiple tannins have broad antibiotic properties via a variety of mechanisms including binding, inactivating and/or precipitating of microbial proteins. Polyphenolic compounds are toxic to microorganisms via non-specific interaction with proteins or by reaction with sulfhydryl groups. Therefore, phytochemical purification and structural analysis studies are required to evaluate the growth inhibitory mechanism(s) and to identify the bioactive and potentiating (or antagonizing) extract components.

CONCLUSION

The aequous Astragalus extract possesses mild inhibitory effects on five different diarrhea and dysentery bacterial triggers. None of the plant extracts affect several harmless gut bacteria. Combinations of extracts with conventional antibiotics elicit several isolated cases of additive or antagonistic effects on bacterial growth inhibition and require further studies into the specific mechanisms responsible.

ACKNOWLEDGEMENT

Financial support for this work was provided by the Environmental Futures Research Institute and the Quality Use of Medicines (QUM) Network, Griffith University, Australia.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ABBREVIATIONS

DMSO: Dimethyl sulfoxide; LC₅₀: The concentration required to achieve 50% mortality; MIC: minimum inhibitory concentration.

REFERENCES

Aqueous Astragalus root extracts had mild inhibitory activity against pathogenic A. faecalis, A. hydrophila, B. cereus, S. newport and S. sonnei bacteria. Combinations of the Astragalus extracts and conventional antibiotics generally produced additive or indifferent interactions. Two cases of antagonistic combinations were detected against B. cereus and S. sonnei. All extracts were determined to be non-toxic as assessed in Artemia nauplii bioassays.

Wenjing Lai was a visiting scholar from Guangdong Pharmaceutical University in China. Her interests lie in the identification of novel therapeutic compounds from traditional medicinal plants and the application of Traditional Chinese Medicine.

Dr Ian Cock leads a research team in the Environmental Futures Research Institute and the School of Natural Sciences at Griffith University, Australia. His research involves bioactivity and phytochemical studies into a variety of plant species of both Australian and international origin, including Aloe vera, South Asian and South American tropical fruits, as well as Australia plants including Scaevola spinescens, Pittosporum phylliraeoides, Terminalia ferdinandiana (kakadu plum), Australian Acacias, Syzygiums, Petalostigmas and Xanthorrhoea johnsonii (grass trees). This range of projects has resulted in nearly 200 publications in a variety of peer reviewed journals.

Dr. Matthew Cheesman is a Lecturer from Griffith University and is a member of the Quality Use of Medicines (QUM) Network. His laboratory group studies the antimicrobial properties of medicinal plants and the mechanisms underlying microbial resistance.

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