

Cultivation practices and phytochemical composition of *A. betulina* and *A. crenulata*: A review



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Background: *Agathosma betulina* (P.J. Bergius) Philans and *Agathosma crenulata* (L.) Pillans are species known as Buchu in Khoi, 'boegoe' or 'bergboegoe' in Afrikaans and 'ibuchu' in isiXhosa. Traditionally, buchu has served as an antipyretic, antispasmodic, diuretic, treatment for constipation, and urinary tract infections.

Aim: The aim of this review is to contribute to the better understanding of the cultivation practices and phytochemical constituents of buchu.

Setting: This review provides an overview of cultivation practices and phytochemical composition of *A. betulina* and *A. crenulata*.

Method: A comprehensive search was conducted on existing literature on the traditional uses, medicinal use, cultivation, and phytochemistry of *A. betulina* and *A. crenulata* in online databases.

Results: Buchu is highly valued for its oil, and used globally in culinary and cosmetic industries for its flavour and aroma. Rising demand for its essential oils and therapeutic products in the early 2000s led to overharvesting, threatening natural populations. To address this, cultivation was encouraged, but limited knowledge of its cultivation methods raises concerns about the impact of further commercial expansion on the species and its ecosystem. Buchu contains bioactive compounds such as diosphenol, menthone, and pulegone, which have demonstrated antibacterial, anti-inflammatory, and antioxidant properties in preclinical studies.

Conclusion: Further research should focus on cultivation practices, non-volatile constituents, *in vitro*, *in vivo*, and clinical research of the species health benefits.

Contribution: Bioprospecting for new health-promoting items needed in the primary healthcare delivery system can benefit from this study's addition to the body of knowledge already available on the two commercially available buchu plants.

Keywords: Buchu; cultivation practices; phytochemical composition; therapeutic properties; overexploitation.

Introduction

Agathosma betulina (P.J. Bergius) Pillans and *A. crenulata* (L.) Pillans, known as buchu, have a long history of use in traditional South African medicine. Buchu is particularly widespread in the mountains of the Western Cape Province. These plants are perennial shrubs, from the Rutaceae family. Among the 150 *Agathosma* species, *A. betulina* (round-leaf buchu) and *A. crenulata* (oval-leaf buchu) are the most prominent, used both locally and internationally, with *A. betulina* being widely available in the market than *A. crenulata* (Abe & Jordaan 2016). *Agathosma betulina* is a re-sprouting, fragrant shrub that grows up to 2 m, while *A. crenulata* is a woody, pungently aromatic, single-stemmed shrub reaching 2.5 m in height (Moolla & Viljoen 2008). The leaves of both species release strong-smelling volatiles from visible pellucid oil glands when crushed (Figure 1) (Moolla & Viljoen 2008). According to Van Wyk (2011), buchu, which was initially utilised by the Khoisan in the 1650s, had a significant role in their culture and has been grown since the 1970s or earlier. Traditionally, buchu has served as an antipyretic, antispasmodic, diuretic, cough remedy, treatment for constipation, prostatitis, rheumatism, and urinary tract infections (Mavimbela, Viljoen & Vermaak 2014;

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Moolla & Viljoen 2008; Sandasi et al. 2023). While the volatile oil components of *A. betulina* and *A. crenulata* have been widely investigated, the non-volatile components have received less attention, despite *A. betulina*'s great commercial value (Moolla et al. 2007). The presence of proteins, glycosides, tannins, saponins, alkaloids, and flavonoids were revealed through phytochemical screening of the ethanol extract. These are non-volatile fraction of *A. betulina* that are not well studied (Chiguvare et al. 2016). There are numerous buchu products in the market, including teas, capsules, and herbal water, which claim to have a medicinal effect because of non-volatile components (Brendler & Abdel-Tawab 2022; Sandasi et al. 2023). *Agathosma betulina* essential oil is recommended for use because of its low concentration of pulegone (< 5%) compared to the > 30% found in *A. crenulata* (Mavimbela et al. 2014). Pulegone is hepatotoxic, its oxidative metabolites (e.g., menthofuran) create covalent bonds with cellular proteins and depleting hepatic glutathione, leading to liver injury (Kleiner 2018). Therefore, this review highlights the important aspects to consider when cultivating buchu plant species.

Methods

A comprehensive literature search on cultivation practices, traditional and medicinal uses, and phytochemical properties of *A. betulina* and *A. crenulata* was conducted using various online databases including Science Direct, Scopus, Google Scholar, and JSTOR. In addition, the Tshwane University of Technology EBSCO Information Services database was also



Source: Moolla, A. & Viljoen, A.M., 2008, "Buchu" – *Agathosma betulina* and *Agathosma crenulata* (Rutaceae): A review', *Journal of Ethnopharmacology* 119(3), 413–419. <https://doi.org/10.1016/j.jep.2008.07.036>

FIGURE 1: Prominent round, translucent oil glands on the abaxial leaf surface.

used for data collection, including the libraries, pre-electronic sources such as books, journal articles, book chapters, theses, dissertation, and other scientific publications.

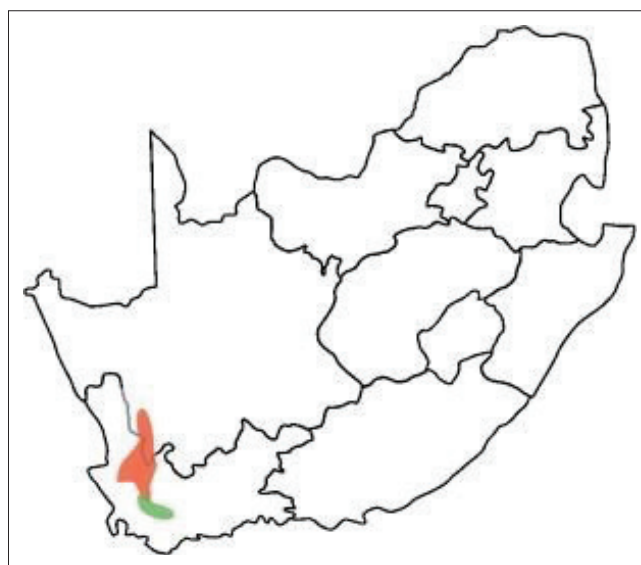
Review findings

Buchu distribution

Buchu is endemic to the Fynbos biome in the Cape Floristic Region areas of the Western Cape Province of South Africa. The plant grows in a Mediterranean region, which is characterised by hot dry summers and winter rainfall ranging from 400 mm to 700 mm (Muller 2015). *Agathosma betulina* distribution range is from the Cederberg Mountains, east of Clanwilliam and Citrusdal, to the Groot Winterhoek Mountains, which include the Piketberg Mountain (Goldblatt & Manning 2000) (Figure 2). The plant thrives in dry environments (between October and March) and can be found in fynbos habitats on sunny rocky sandstone slopes at altitudes ranging from 300 m to 700 m above sea, where other crops will not succeed (Moolla & Viljoen 2008). *Agathosma crenulata* grows on lower slopes from the Paarl area to the Kleinrivier Mountains in the Overberg to the province's east, on lower slopes and valleys on more moist sites (Goldblatt & Manning 2000).

Taxonomic and botanical description

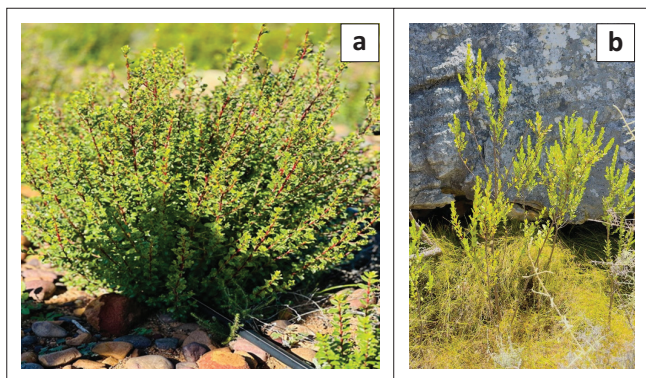
Buchu nomenclature has evolved, and species identification was challenging because of historical references that omit taxonomic sources. Multiple taxonomists named and re-named the species, in 1756 Linné first recorded the genus as *Diosma*, specifically *D. crenulata* and *D. crenata*, followed by Thunberg in his *Prodromus*, later Ecklon and Zeyher provided detailed



Source: Mavimbela, T., Viljoen, A. & Vermaak, I., 2014, 'Differentiating between *Agathosma betulina* and *Agathosma crenulata*—A quality control perspective', *Journal of Applied Research on Medicinal and Aromatic Plants* 1(1), e8–e14. <https://doi.org/10.1016/j.jarmap.2014.04.002>

FIGURE 2: Geographical distribution map of *A. betulina* or round-leaf 'buchu' (top shading [red]) and *A. crenulata* or oval-leaf 'buchu' (bottom shading [green]) native to South Africa.

botanical and geographical data and introduced the genus as *Barosma*. Later, the taxonomist, Pillans, re-named the genus *Agathosma* in 1950 (Brendler & Abdel-Tawab 2022). Buchu is an evergreen perennial shrub with woody branches and small, pale green leaves 20 mm long, leathery, and glossy, with a blunt, strongly curved tip, and a finely toothed margin (Figure 3). *Agathosma betulina* has round-flat leaves (Figure 4), while *A. crenulata* has long oval leaves (Figure 4) and this remains the only way to tell the two are different (Mavimbela et al. 2014). The leaf margins and lower leaf surface are scattered with translucent oil glands (Moolla & Viljoen 2008; Witbooi et al. 2017). The leaves are strongly aromatic, with peppermint-like odour and the oil is golden in colour (Sandasi et al. 2023). It has large flowers, typically solitary, star-shaped with five petals, found in the leaf axils and varies in colour from white to purplish-pink. The two species bears brown, five chambered with horn-like tips fruits, producing one seed per capsule after flowering between August and September (Van Wyk 2017; Witbooi et al. 2017). The seeds are small, oval-shaped, and have a dark brown to black colour (Figure 5).



Source: Photographs taken by N.M. Mashabela; a) 13 June 2024 and b) 22 February 2025. Used with permission. No unauthorised duplication allowed

Figure 3: Buchu *Agathosma betulina* shrub growing in the wild: (a) under cultivation (buchu moon farm) and; (b) natural habitat (Groot Winterhoek: 32°59' 53 S" 19°03' 29.0" E).

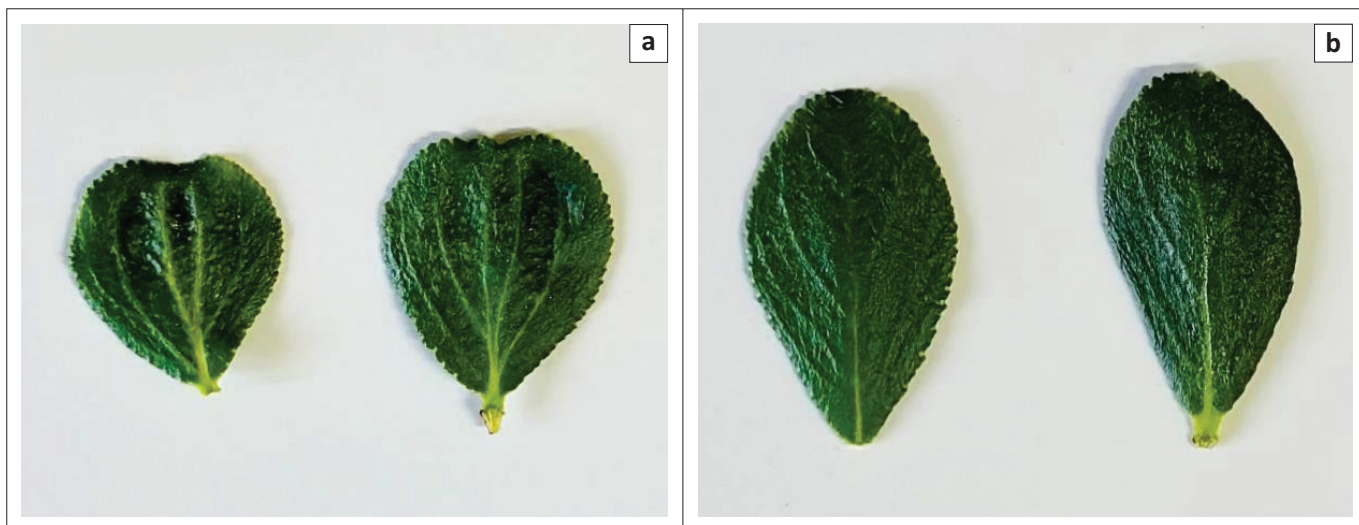
Growth requirements of buchu

Buchu is a member of the fynbos vegetation, with a fire-prone life span of 10–15 years, turning woody as it ages. The two species prefer full sun for successful growth and development (Goldblatt & Manning 2000). The commercial cultivation of buchu started in the 1920s following research work by the Kirstenbosch National Botanical Garden results (Witbooi 2013). However, information on the growth requirements of buchu, especially on water, soil, and nutrients, is still scanty. Numerous species of buchu are limited to specific soil types (acidic), aspects, elevations, and climates. Buchu grows naturally on south-west facing slopes at a specified altitude range of 1737 to 2028 m above sea level (Ntwana 2007). *Agathosma betulina* prefers higher elevations with slightly cooler, drier climates, well drained rocky soils in the fynbos, while *A. crenulata* prefers lower elevations near rivers and in moist, fertile soils, although it is still found in fynbos (Muller 2015).



Source: Photograph taken by N.M. Mashabela; 03 February 2025. Used with permission. No unauthorised duplication allowed

Figure 5: *Agathosma betulina* seeds taken in Skimmelberg.



Source: Photographs taken by N.M. Mashabela; 31 January 2025 (a and b). Used with permission. No unauthorised duplication allowed

Figure 4: The oval and flat leaves: (a) *Agathosma betulina*; (b) *Agathosma crenulata*.

Soil requirements

Buchu thrives in soils similar to those of other fynbos plants, which are generally infertile, nutrient-poor, coarsely graded, and acidic (Manning 2018; Witbooi 2013). The ecology of the vegetation of the infertile sandy soil is delicate; disturbance and limited range endanger the species (Silveira et al. 2016). Fynbos soil is nutrient-deficient because it originates from low-nutrient rocks, primarily quartzites and hard sandstones (Goldblatt & Manning 2000). The mountain soils where buchu grows are typically shallow, rocky, sandy, and acidic (Ntwana 2007; Ntwana, Agenbag & Langenhoven 2011). It grows naturally in soils that range from sandy to sandy loam (De Villiers 2007). However, according to Ntwana (2007), light-to-medium loam soils that are deep reddish are ideal for buchu growth. Buchu plants do not tolerate saline soils; a minimum of 600 mm of well-drained soil is required for cultivation (Ntwana 2007). Ntwana et al. (2011) reported that soil analyses were carried out in 11 sites of the Cederberg Mountains where buchu grows naturally, and a p -value below 8 mg kg^{-1} (Bray II) was found (De Villiers 2007; Ntwana et al. 2011). The environment in which buchu grows naturally was found to have moderate amounts (0.51%) of potassium (K) (Ntwana et al. 2011). The calcium content was found to be low from all the sites ($0.14 \text{ cmol } [^+] \text{ kg}^{-1}$). The soil mineral analysis indicated low levels of sodium and exchangeable magnesium. Furthermore, the levels of manganese ranged between 4 mg kg^{-1} and 29.8 mg kg^{-1} at all the sites. Manganese levels are considered acceptable for plants between the range of 5 mg kg^{-1} and 140 mg kg^{-1} (Sillanpää 1982). Levels of copper were significantly low ($<1 \text{ mg kg}^{-1}$) (Ntwana et al. 2011).

Ntwana, Agenbag and Langenhoven (2013) found that growth and the highest biomass accumulation were achieved in acidic pH treatments, suggesting that buchu performs well in such environments. Buchu plants grow on acidic soils with pH levels ranging from 3.5 to 4.5, with a maximum of 5.5; pH levels between 7 and 7.99 are not advised for healthy growth and high yields because they lead to stunting and less bushy plants and, consequently, lower yields (Ntwana et al. 2013). The pH range of 6–6.99 was determined to be the overall upper limit for appropriate growth, while 4–4.99 was shown to be the ideal pH range; however, at this ideal pH range, the pulegone concentration was higher than the permitted range of 0–5% (Ntwana et al. 2013), thus, decreasing the marketable quality of the oil.

Climatic requirements

Buchu thrives in the Western Cape's Mediterranean environment, with hot dry summers and rainy winters from May to September (Muller 2015). The winter season in this area is typically pleasant, apart from elevated regions where night temperatures may drop below freezing and periodic snowfalls on mountain summits that can last for weeks. The rainfall regime in the Cape Fynbos region varies. The rainfall pattern is orographic, meaning that precipitation increases with altitude and the rain shadow effect is more prominent

than typical (Bradshaw & Cowling 2014). These regions experience 400 mm – 1700 mm of yearly precipitation throughout the winter (Van Wilgen et al. 2010).

Water requirements

Witbooi (2013) observed that buchu needs a moderate-to-high water supply. Buchu plants require an average of 6000 mL – 7000 mL of water per week by drip irrigation during the summer months (Muller 2015). Mature plants require no more than 5000 mL of water per plant, once a week in the evening (DAFF 2011). Irrigating at night lowers the risk of fungal diseases and increases water absorption. Drip irrigation is recommended because it allows control over the volume and location of water per plant and lowers evaporation loss in windy places, among other factors (DAFF 2011). Seedling establishment requires adequate water; therefore, it is best to transplant after good rains. Irrigation water should be of high quality, with minimal chlorine and salinity (DAFF 2011).

Plant nutrition

Research on buchu's water and nutritional needs is still emerging, but balanced fertilisation is recommended to support growth by ensuring essential nutrients are supplied (De Villiers 2007). However, commercial growers lack specific fertility guidelines. Fynbos soils in the Mediterranean climate are nutrient-poor, particularly in macronutrients such as nitrogen, phosphorus, and potassium, as well as micronutrients such as iron and magnesium (Abanda, Compton & Hannigan 2011; Sardans & Penuelas 2013). Fynbos soils often have low nitrogen (below 5 mg/kg) and phosphorus (2 mg/kg – 10 mg/kg) levels, which are inadequate for optimal plant growth (De Villiers 2007). Phosphorus can enhance buchu growth and essential oil yield, with recommended levels for *A. betulina* at 10 mg/kg – 15 mg/kg phosphorus and 10 mg/kg – 15 mg/kg nitrogen to avoid excessive vegetative growth (De Villiers & Du Preez 2005). The nutrient-poor fynbos biome, shaped by recurring fires and nutrient-leached soils, evolved to adapt to such conditions (Fouche 2023; Linder 2003). Fire is crucial for mineralisation, releasing nutrients from biomass back into the soil (Kraaij & Van Wilgen 2014; Van Wilgen et al. 2010). After fires, fynbos soils experience nutrient flushes, particularly of nitrogen and phosphorus, which temporarily boosts soil fertility (Schaller et al. 2015).

Plant propagation

Small-scale farmers, home gardeners, and medicinal plant nurseries frequently employ the conventional propagation techniques, which include vegetative and seed multiplication. However, these techniques are frequently hindered by issues such as stem cutting rooting problems, seed dormancy, and loss of seed viability (Fajinmi, Olarewaju & Van Staden 2023). Buchu seed germination is difficult, and cuttings have a lower rooting percentage (25%) than the commercially viable 40% (Blomerus 2002; Karsen 2003; Witbooi et al. 2017).

Seed propagation

Buchu's propagation is limited by seed availability; the seeds are dispersed through ballistic dispersal upon ripening (Ntwana 2007). Harvesting seeds from fully mature capsules between October and December yields better germination rates and to ensure a good percentage (40–60) of viable seeds, regular intervals are recommended as capsules shed seeds over time (Karsen 2003; Moolla & Viljoen 2008; Ntwana 2007). Seed harvesting must occur at the optimal period (November–December) for maximum seed viability (Littlejohn 2001). To promote germination, smoke treatment should be conducted in a covered environment with adequate light during the month of March, air movement, and a humid environment, as fynbos species such as buchu are adapted to fire (Xaba & Lucas 2009). Fire events in late summer to early autumn stimulate germination across many fynbos species (Brown & Duncan 2006; Kraaij & Van Wilgen 2014).

Vegetative propagation

Buchu can be propagated from cuttings (Karsen 2003). The advantage of cuttings over seedlings is that they grow into larger flowering plants more quickly. Semi-hardwood cuttings with a length of 50 mm – 70 mm from the current season's growth were harvested from September to November:

To prepare the cuttings, cuts are carefully made below a node, and the bottom third of the leaves are removed. Cut ends are dipped in auxin to promote rooting. The cutting trays were placed in a well-aerated propagation unit with a bottom heat of 24 °C and intermittent misting. Rooting occurred in 9 to 11 weeks. (Karsen 2003)

In addition Karsen, found that applying 500 ppm – 1000 ppm indole butyric (IBA) resulted in a rooting percentage of 40% – 45% and concluded that a rooting success of 40% is commercially viable. For successful nursery propagation, a minimum rooting percentage of 80% is considered optimum (Malan & Blomerus 2012). According to Karsen (2003), 'buchu cuttings are naturally slow to root, hence poor rooting results are connected to the cutting's ability to live long enough for rooting to occur'. Blomerus, Coetzee and Reinten (2001) found that the timing of the cutting is important; this is achieved after flowering when the plant produces new shoots, which are ideal for tip-, stem-, or heel cuttings. Another factor that may contribute to poor rooting in cuttings is the challenge of managing infections, even with proper sanitation measures (Malan & Blomerus 2012).

Micropropagation

Witbooi et al. (2017) conducted a study with the goal of creating a micropropagation protocol for *A. betulina*. Through physical scarification and smoke-water treatments, the scientists discovered an efficient *in vitro* seed germination strategy that resulted in healthy seedlings that could be transplanted *ex situ*. In buchu nodal explants, a highly significant multiple shoot multiplication was seen utilising 1/2 Murashige and Skoog (1962) in addition to plant growth regulators (PGRs). After testing three PGRs, they discovered

TABLE 1: Seasonal variations in pulegone levels of *Agathosma betulina* essential oil as percentage of total fractions measured.

Months	Pulegone
January	4.8 ± 1.3
February	1.5 ± 0.2
March	1.8 ± 0.0
April	1.2 ± 0.1
May	1.7 ± 0.0
June	1.2 ± 0.3
July	1.3 ± 0.1
August	3.5 ± 0.8
September	4.0 ± 0.2
October	11.5 ± 3.7
November	10.9 ± 1.4
December	3.8 ± 0.6

Source: Ntwana, B., 2007, 'Growth, mineral content and essential oil quality of buchu (*Agathosma betulina*) in response to pH under controlled conditions in comparison with plants from its natural habitat', Doctoral dissertation, Cape Peninsula University of Technology.

that 2, 4-D, at a dose of 4.5 µM, was the most effective for initiating shoots. The highest percentage of shoot proliferation was observed in explants grown on half-strength MS medium supplemented with a combination of 1-naphthaleneacetic acid (NAA) and *N*⁶-benzyladenine (BA). Phytochemical analysis revealed that the callus from the nodal explants of buchu grown on MS media supplemented with NAA had the highest accumulation of limonene.

Harvesting

Harvesting buchu leaves at an inappropriate time diminishes their quality and shortens the plant's lifespan (Ntwana et al. 2013). Buchu should be collected throughout the months of January to March (De Ponte Machado 2003). In addition, in an earlier study it was reported that the optimal time to harvest is in February. This is because of the low pulegone concentration at this time of year (Table 1). Pulegone levels are influenced by different factors such as time of harvesting, the nutrition levels, and plant age (Dlamini & Moyo, 2017; Ntwana et al. 2013). To ensure sustainable harvesting, guidelines recommend avoiding collection during flowering, allowing sufficient regrowth, and limiting harvest to once every 2 years (Ntwana 2007). However, with the growing demand, this is not commercially sustainable (Crouch & Van Wyk 2010). *Agathosma betulina* is a re-sprouter; it can be sustainably harvested by cutting the shoots and branches above the base by the internodes, thus allowing new growth. *Agathosma crenulata* is a re-seeder and has a slow recovery; therefore, a cutting is made carefully to allow enough growth for seed production.

Pests and diseases

Information about diseases and pests that affect buchu is scarce. The most common pests or insects seen on *A. betulina* plants are cutworms, soft scale, plant lice, hard scale (dopluis), root-knot nematodes, snails, ants, leaf miners, stem-borer beetles, and harvester termites (DAFF 2011). Buchu is sensitive to the soil-borne fungus *Phytophthora cinnamomii* and *Fusarium* wilt disease, both of which attack fynbos species and cause plant harm (Xaba & Lucas 2009).

Phytochemistry

When planning to produce buchu, one of the aspects that need to be considered is the essential oil quality (Ntwana 2007; Tadmor et al. 2002). Higher education, growing consumer health and environmental concerns, sustainable harvesting practices, and genetic diversity loss have all contributed to the desire for natural plant products that are effective, safe, and clean (Trinder-Smith & Raimondo 2016). It is also vital to realise that overseas markets expect high-quality products. As a result, buchu quality control is often a critical measure in its production, given that the major consumers of buchu are primarily in the international markets (Baard 2023).

Volatile constituents

Buchu has an essential oil that is characterised by a peppermint-like aroma and known to have mild antiseptic and weak diuretic qualities (Ntwana 2007). Large circular cells beneath the leaf's epidermis are where the volatile oil builds up and is contained; however, *A. betulina* produces a larger percentage of this oil than *A. crenulata* (Ntwana 2007). Isomenthone, menthone, diosphenol, pulegone, limonene, 4-hydroxydiosphenol, 8-mercapto-p-menthan-3-one, 8-acetylthio-p-menthan-3-one, 8-methylthio-p-menthan-3-one, pseudo-diosphenol, and 1-hydroxydiosphenol are the major marker compounds found in the essential oil profile of *A. betulina* (Van Wyk 2011). *Agathosma crenulata* was found to contain limonene, menthone, a trace of diosphenol, and large amounts of l-pulegone (Moolla & Viljoen 2008). Table 2 presents a list of key compounds found in the two commercial buchu species.

The buchu volatile component, monoterpene diosphenol, is thought to be the reason for its urinary tract antiseptic actions (Ntwana 2007). Two chemotypes of *A. betulina* have been identified: the diosphenol chemotype and the isomenthone chemotype (Collins et al. 1996). The diosphenol chemotype is characterised by high levels of Ψ -diosphenol and diosphenol (exceeding 0.5% and 12%, respectively) and low

concentrations of isomenthone and menthone (below 29% and 9.6%, respectively). In contrast, the isomenthone chemotype exhibits an opposite profile, with isomenthone and menthone concentrations exceeding 31% and 27%, respectively, and diosphenol levels below 0.14% (Collins et al. 1996; Posthumus et al. 1996; Viljoen et al. 2006). Although the diosphenol chemotype is preferred for its elevated diosphenol content, both chemotypes produce highly aromatic essential oils containing less than 5% pulegone (Blommaert & Bartel 1976; Moolla & Viljoen 2008).

The geographical distribution of these two chemotypes is different. The isomenthone chemotype is primarily found on the northern and western slopes of the Piketberg Mountains, while the diosphenol chemotype is primarily found in the mountain's surroundings, Citrusdal (Ntwana 2007). Collins et al. (1996) observed no significant relationship between oil content and chemotype geographic origin. These authors determined that genetics are more important than environmental variables. The conclusion was thus made because all *A. betulina* plants with low diosphenol isomers were discovered in the Piketberg mountain range, but not all Piketberg plants had low diosphenol content. *Agathosma crenulata* is not suited for medicinal utilisation because it contains less diosphenol and more pulegone (Collins et al. 1996). *Agathosma betulina* oil has a 53:47 equilibrium mixture of Ψ -diosphenol and diosphenol as well as pulegone, limonene, and menthone as major constituents (Sandasi et al. 2023; Schneider & Viljoen 2002).

Non-volatile constituents

The non-volatile fraction of *A. betulina* is not well studied; however, phytochemical screening of the ethanol extract revealed the presence of various metabolites (Chiguvare et al. 2016).

Flavonoids such as diosmin, rutin, kaempferol, quercetin, and hesperidin were identified in the methanol extract of buchu (Brendler & Abdel-Tawab 2022). *Agathosma crenulata* contains a higher concentration of rutin and a lower concentration of quercetin-dimethyl ether-glucoside as

TABLE 2: Relative percentage (%) and major compounds identified in the essential oil of *A. betulina* and *A. crenulata*.

Compounds	<i>A. betulina</i>	<i>A. crenulata</i>	References
Diosphenol	2.5	0.1	Viljoen et al. (2006)
Pseudo-diosphenol	2.9	0.1	Viljoen et al. (2006)
Limonene	10–25	13.4	Sandasi et al. (2010) and Viljoen et al. (2006)
Pulegone	< 5	34.9	Sandasi et al. (2010) and Viljoen et al. (2006)
Cis-isopulegone	0.2	0.5	Viljoen et al. (2006)
Trans-isopulegone	0.5	1.6	Viljoen et al. (2006)
Menthone	29.2	16.6	Viljoen et al. (2006)
Isomenthone	4.57–29.07	7.3	Collins et al. (1996) and Viljoen et al. (2006)
Cis-trans-8-mercapto-p-menthan-3-one	2–3.5	0.1	Collins et al. (1996) and Viljoen et al. (2006)
Terpinen-4-ol	0.7	0.5	Viljoen et al. (2006)
Trans-dihydrocarvone	0.2	0.4	Viljoen et al. (2006)
Carvone	Trace	0.1	Viljoen et al. (2006)
Myrtenyl acetate	0.3	0.4	Viljoen et al. (2006)
1,8-cineole	2.7	2.4	Viljoen et al. (2006)
8-mercapto-menthan-3-one	0.1–4	-	Sandasi et al. (2023)

Note: Please see the full reference list of the article, Mnisi, N.H., Gununu, R.P., Mashabela, N.M., Bvenura, C., Mulidzi, R.A., Blomerus, L. et al., 2025, 'Cultivation practices and phytochemical composition of *A. betulina* and *A. crenulata*: A review', Journal of Medicinal Plants for Economic Development 9(1), a281. <https://doi.org/10.4102/jomped.v9i1.281>, for more information.

A. betulina, *Agathosma betulina*; *A. crenulata*, *Agathosma crenulata*.

compared to *A. betulina*. These flavonoids have antioxidant properties and guard the cells against the harmful unstable oxygen molecules (Brendler & Abdel-Tawab 2022).

Therapeutic and nutritional value of buchu

The *Agathosma* species is rich in flavonoids such as diosmin, hesperidin, rutin, and quercetin, along with mucilage and resins, which exhibit strong antioxidant effects (Li & Schluesener 2017; Mahmoud et al. 2019). These compounds function through various mechanisms to neutralise free radicals (Moolla & Viljoen 2008; Moolla et al. 2007). Buchu essential oils and extracts show activity against specific pathogens, including *Klebsiella pneumoniae*, *Staphylococcus aureus*, *Candida albicans*, and *Bacillus cereus*, with greater effectiveness against gram-positive bacteria than gram-negative ones (Moolla et al. 2007; Viljoen et al. 2006). These oils also influence biofilm formation by hindering bacterial attachment. Several researchers have found that *Agathosma* species contain coumarins and phenolic compounds with benzene and α -pyrone rings, which exhibit antimicrobial properties by stimulating macrophages (Moolla et al. 2007; Sandasi, Leonard & Viljoen 2008; Viljoen et al. 2006).

The oil distilled from buchu leaves is therapeutically beneficial, notably for treating kidney and urinary tract infections, as well as haematuria and prostatitis (Moolla & Viljoen 2008). Diospenol is responsible for the diuretic effects of buchu, with both diospenol and flavonoids contributing to increased urine production by irritating the gallbladder (Watt & Breyer-Brandwijk 1962). Buchu oil has limonene, which is known for its anti-inflammatory effects. The essential oils have been shown to inhibit leukotriene synthesis by blocking the enzyme 5-lipoxygenase. Limonene also helps reduce the biosynthesis of cyclooxygenase 1 and 2 (Moolla et al. 2007; Van Wyk et al. 2011; Viljoen et al. 2006). The monoterpene thiol 9-mercapto-p-menthan-3-one is a key component contributing to buchu oil's distinctive aroma. It plays a crucial role in the plant's scent and flavour as a sulphur-containing terpene (Moolla et al. 2007). Buchu has a naturally minty, sweet berry, apricot, peach, and green herbal taste, with its oils commonly used in perfumes and colognes (Moolla & Viljoen, 2008; Moolla et al. 2007). The *Agathosma* species is also used in the treatment of arthritis and rheumatism by reducing uric acid levels. In addition, it is used to treat gastrointestinal problems, including flatulence, diarrhoea, and nausea (spasmodic effects) (Bajpayee et al. 2012; Moolla & Viljoen 2008; Moolla et al. 2007).

Implications and recommendations

Discussion and future research

Buchu (*A. betulina* and *A. crenulata*) has a long history of medicinal use among South Africa's indigenous people, which drives its current popularity. Rising demand from

traditional healers, herbalists, researchers, and international markets has led to a decline in wild populations, posing a risk of extinction if unsustainable harvesting continues (Trinder-Smith & Raimondo 2016). Therefore, sustainable cultivation is essential as an optimal conservation strategy, supporting successful commercialisation. However, research on cultivation practices is still lacking. Ntwana et al. (2013) studied the effects of pH on the growth, mineral content, and essential oil quality of *A. betulina* under controlled conditions, which has improved our understanding of its growth across various pH levels. Approximately 20000 plants can be cultivated per hectare, yielding about 1% oil (Sandasi et al. 2023). The estimated annual production per annum is 300 tonnes, with 50 tonnes being sold on the domestic market and 250 tonnes being exported (Sandasi et al. 2023). Despite documented phytochemical differences, research gaps remain regarding buchu's medicinal benefits and cultivation. Addressing this gap is crucial for advancing research and reducing the overharvesting of wild buchu plants. The antioxidant compounds in *A. betulina*, such as hesperidin and diosmin, show potential benefits for reducing degenerative disease risks, including cancer and cardiovascular diseases. Further studies on these benefits could support its use as a preventive health supplement.

Conclusion

Buchu has a long history as a remedy for various ailments and is undoubtedly one of South Africa's most significant medicinal plants and export products. Despite its well-established use, the cultivation practices and biological activity of buchu remain underexplored. While pharmaceutical research has been conducted on buchu, most of these studies are *in vitro* and few have verified its traditional uses. Unlike the detailed data available on the volatile (essential oil) components, the non-volatile compounds of *A. betulina* and *A. crenulata* have not been thoroughly studied. The growing interest in buchu for the flavour and fragrance industry, both locally and internationally, is expected to drive further research into this versatile and ethnomedicinally important species. Although the benefits of buchu have been recognised for a long time, its use has yet to become mainstream because of the need for definitive research to validate its advantages. Sustainable cultivation of this plant would facilitate more detailed research in a shorter timeframe. Given its numerous benefits, it would be worthwhile to investigate all its properties to maximise its potential while also ensuring the conservation of this valuable medicinal plant.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

N.H.M. designed the study, was involved in the investigation and data collection (articles), carried out a comprehensive review, and drafted the original article. R.P.G. was involved in the supervision, providing resources, methodology, reviewing, and editing. C.B. was involved in methodology formation, supervision, and writing – reviewing and editing. N.M.M. was involved in the methodology process, visualisation, validation, securing resources, supervision, and writing – reviewing and editing of the article, as well as funding acquisition. R.A.M. was involved in the supervision, reviewing and editing, and funding acquisition. L.B. and P.A.K. were responsible for the writing, reviewing, and editing of the article. M.M.M., S.A., and D.M. were responsible for reviewing and editing the article and funding acquisition.

Ethical considerations

Ethical waiver to conduct this study was obtained from the Agricultural Research Council (ARC) editor in chief dated 05 February 2025.

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Data availability

The data used to support the findings are available in the online database.

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