Vachellia xanthophloea (Benth.) P.J.H.Hurter (fever tree): Traditional and present uses, and future potential

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Rebiew

Abstract

Background: *Vachellia xanthophloea* (Benth.) P.J.H.Hurter was traditionally associated with malaria and early pioneers were convinced that the species was the cause of fever and malaria. Even today, the species is commonly known as the "fever tree" throughout its distributional range in eastern and southern Africa. However, there are many other uses, some of them known since prehistoric times. Therefore, the present review compiles existing information about traditional and present uses, and further use potential and applications of *V. xanthophloea.*

Methods: Documented uses and ethnopharmacological properties of *V. xanthophloea* were obtained from online databases such as JSTOR, Scopus, PubMed, Science Direct and Google Scholar as well as pre-electronic literature sources obtained from the university library.

Results: This study showed that *V. xanthophloea* is a multipurpose species characterized by a variety of ecosystem services and goods such as provisioning, regulating, cultural and supporting services. *Vachellia xanthophloea* is used as medicinal plant against human and animal diseases in four countries, representing 36.4% of the countries where the species is indigenous. The phytochemical evaluation of the plant revealed that it contains alcohols, aldehydes, alkanes, alkenes, benzene derivatives, carboxylic acids, esters, flavonoids, ketones, phenols, phthalates, polycyclic aromatic hydrocarbons, triterpenoids and volatile oils.

Conclusions: Being easy to propagate by seed and also fast growing, *V. xanthophloea* has potential as medicinal plant, source of fodder, fuelwood, timber, tannin, ornamental, live fence, and the species plays an important role in the reclamation of degraded areas.

Keywords: Fabaceae, Indigenous knowledge, Leguminosae, Tropical Africa, *Vachellia xanthophloea*

Background

Vachellia xanthophloea (Benth.) P.J.H.Hurter (Figure 1) is a multipurpose tree. As a multipurpose plant species, almost all of its different parts are used as sources of ecosystem services and goods that support human well-being and survival. *Vachellia xanthophloea* is widely used as an important source of timber in eastern and southern Africa (Lemmens 2008). The timber is used for poles, fence posts, construction purposes, as source of charcoal and firewood (Kiringe & Okello 2005, Lovett *et al.* 2006, Manyatsi & Hlophe 2010, Nahashon 2013, Dharani 2019, Mbuvi *et al.* 2019). The wood obtained from *V. xanthophloea* is hard, heavy, strong, with a coarse, even texture which is suitable for planks and general purpose, but inclined to crack unless thoroughly seasoned (Lemmens 2008). The leaves, branches, twigs and pods of *V. xanthophloea* are browsed by game and livestock, and often harvested from the wild and used as fodder or the species planted around homesteads as fodder (Nahashon 2013, Van Wyk & Van Wyk 2013, Dharani 2019, Mbuvi *et al.* 2019, Mudzengi *et al.* 2020, Ratemo *et al.* 2020). Literature studies revealed that the leaves, branches and pods of *V. xanthophloea* are excellent fodder and feed sources for poultry as these plant parts are characterized by crude proteins, fibre, macro-minerals such as calcium, magnesium, phosphorus and potassium and micro-minerals such as copper, iron, manganese and zinc (Nassoro 2014, Kolobe *et al.* 2022).

Figure 1. *Vachellia xanthophloea*: A: showing plant habit, B: a branch showing leaves and thorns and C: a branch with leaves and flowers (Photos: BT Wursten)

Vachellia xanthophloea is widely cultivated as shade, ornamental, street tree, hedge or live fence throughout its distributional range in eastern and southern Africa (Palgrave 2002, Paumgarten *et al.* 2005, Lovett *et al.* 2006, Orwa *et al.* 2009, Kuruneri-Chitepo & Shackleton 2011, Schmidt *et al.* 2017, Dharani 2019, Van Wyk 2019). Venter & Venter (2015) argued that the species is categorized as one of the best ornamental trees in the region for the garden, urban streets and resting places in national parks and private game reserves. The species also provides nesting sites for birds and the tree does not have an aggressive taproot, but because of its size, should not be planted close to buildings (Venter & Venter 2015). *Vachellia xanthophloea* was introduced in Egypt from South Africa in the 20th century as an ornamental plant (Bircher 1960; Hassan & Hamdy 2021) and the species is now categorized as a weed of pastures in Australia (Randall 2017), Taiwan, India and California (Orwa *et al.* 2009). *Vachellia xanthophloea* is also grown for the flowers that yield a honey of good quality, nitrogen fixing, mulching, to curb soil erosion and also play an important role in the reclamation, rehabilitation of degraded areas or river-bank stabilization (Orwa *et al.* 2009, Kahuthia-Gathu *et al.* 2018a,b, Dharani 2019). In Kenya, the branches, stems or twigs of *V. xanthophloea* are used as chewing sticks or toothbrushes to clean the teeth (Ngari *et al.* 2014). The different plant parts of *V. xanthophloea* are used in many traditional medicines throughout the distributional range of the species (Dold & Cocks 2002, Mankga *et al.* 2013, Nahashon 2013, Mwaura *et al.* 2020, Mbongwa *et al.* 2021). *Vachellia xanthophloea* produces a gum, which occurs in large quantities on the trunk, and is reportedly edible, and is also eaten by wild animals such as monkeys (Lemmen 2008) and Senegal bushbaby (*Galago senegalensis*) (Kingdon *et al.* 2013). A unique parasitic flowering plant, *Sarcophyte sanguinea* Sparm. subsp. *sanguinea* (Balanophoraceae family) grows on the roots of *V.*

xanthophloea (Van Wyk 2008). *Vachellia xanthophloea* is regarded as a host for several beetle species (Kahuthia-Gathu *et al.* 2018a,b), butterflies and moths (Agassiz & Harper 2009).

Vachellia xanthophloea is an important source of bio-tannins in eastern and southern Africa (Kuria *et al.* 2016, China *et al.* 2020, Duraisamy *et al.* 2020, Cheloti *et al.* 2022, 2023a). Duraisamy *et al.* (2020) argued that vegetable tannins are ecologically friendly and more sustainable than conventional chrome tannins. Vegetable tannins confer unique attributes to skins and hides, producing compact, full and easily embossable leather that possesses better water permeability, strength, stability and moulding properties (Adiguzel-Zengin *et al.* 2017, Cheloti *et al.* 2023a). Similarly, a study by Cheloti *et al.* (2023a) showed that the tannin from *V. xanthophloea* produced excellent leather, which is heavy, firm, durable, hard with a reddish tinge, exhibiting mechanical properties such as tensile strength, grain crack and ball burst that are comparable to the conventional tannin sources such as mimosa. Experimental tests conducted in Kenya and Tanzania, showed that tannin extracted from *V. xanthophloea* is comparable to tannin extracted from *Vachellia nilotica* (L.) P.J.H.Hurter & Mabb. (synonym *Acacia nilotica* (L.) Willd. ex Delile) and *A. mearnsii* De Wild. (Kuria *et al.* 2016, China *et al.* 2020), which are commercial sources of tannins (Dunlop 2005, Fagg & Mugedo 2005). Due to the growing demand for vegetable-tanned leather as a result of the growing importance and value of renewable resources, chrome-free and greener chemical processing options in comparison with synthetic products, V. *xanthophloea* is a potential candidate for the commercial production of tannins in the tropics and throughout the globe (Kuria *et al.* 2016, China *et al.* 2020, Duraisamy *et al.* 2020, Cheloti *et al.* 2022, 2023a). It is therefore, within this context that the current study was undertaken, aimed at compiling information about traditional and present uses, and further use potential and applications of *V. xanthophloea.* This is a comprehensive scientific review aimed at providing the baseline scientific and ethnobotanical data and additional information that can enhance further research, cultivation, and use of *V. xanthophloea.*

Materials and Methods

Literature search on medicinal uses, botanical, phytochemical and pharmacological properties of *V. xanthophloea* throughout its distributional range in eastern and southern Africa was conducted using online databases such as JSTOR, Scopus, PubMed, Science Direct and Google Scholar. In addition to this, pre-electronic sources such as books, journal articles, dissertation, book chapters, theses, and other scientific articles obtained from the University library were used. Keywords used in the search included *"*biological activities of *Vachellia xanthophloea*", "pharmacological properties of *Vachellia xanthophloea*", "ethnobotany of *Vachellia xanthophloea"*, "medicinal uses of *Vachellia xanthophloea*", "phytochemistry of *Vachellia xanthophloea*" and "traditional uses of *Vachellia xanthophloea".*

Results and discussion

Morphological description and taxonomy of *Vachellia xanthophloea*

The genus *Vachellia* Wight & Arn. belongs to the subfamily Mimosoideae of the Fabaceae (Leguminosae), often referred to as the bean, legume or pea family. Over the years, the genus *Vachellia* together with other genera such as *Acaciella* Britton & Rose, *Mariosousa* Seigler & Ebinger and *Senegalia* Raf. were classified as part of the larger and polyphyletic *Acacia* Mill. genus (Moore *et al.* 2011, Kyalangalilwa *et al.* 2013, Dyer 2014). A reclassification of the genus *Acacia* was undertaken about 20 years ago, incorporating data from molecular, anatomical, biochemical and morphological studies (Carruthers & Robin 2010). The genus that is currently referred to as *Acacia* represents the majority of Australian species and a few species that have been recorded in the Pacific Islands, Réunion and southeast Asia (Maslin 2008). The majority of species recorded outside Australia and a small number of Australian species are classified into *Acaciella, Senegalia* and *Vachellia* (POWO 2024). Taxonomically, genus *Vachellia* is closer to *Senegalia*, the main difference is that *Senegalia* has spicate inflorescences (flowers in spikes), prickles and the stipules are non-spinescent while *Vachellia* has capitate inflorescences (round and head-like flowers), spinescent stipules (thorns), pollen collumelae and involucre on peduncle (Kyalangalilwa *et al.* 2013, Dyer 2014). Species belonging to the *Vachellia* genus are trees or shrubs, sometimes climbing and always armed with paired stipular spines at the nodes that can either be straight, deflexed or weakly falcate (Seigler & Ebinger 2005, Seigler *et al*. 2006, Kyalangalilwa *et al.* 2013), restricted to dry savannas and semi-desert scrub habitats (Timberlake *et al.* 1999, Dharani 2006, Kyalangalilwa *et al.* 2013). Of the 163 species belonging to the *Vachellia* genus, 83 species are native to Africa, Madagascar and the Mascarene Islands, 52 species have been recorded in the Americas, 32 species in Asia and 9 species are native to Australia and the Pacific Islands (Thiele *et al.* 2011).

The genus name "*Vachellia*" is in honour of Reverend George Harvey Vachell (1789 to 1839), a British plant collector who discovered a number of new taxa, and also served as a Chaplain to the British East India company's factory at Canton and Macao (Hankey & Stern 2002). The specific name "*xanthophloea*" is based on two Greek words, "*xanthos*" meaning "yellow"

and "*phlois*" meaning "inner bark" (Palmer & Pitman 1972). Therefore, the specific name "*xanthophloea*" implies that the species has large amounts of the photosynthetic yellow–green accessory pigment "xanthophyll" in the secondary phloem of the inner bark (Williams *et al.* 2007). *Vachellia xanthophloea* is commonly known in English as "fever tree", "fever tree *Acacia*", "fever tree thorn", "Naivasha thorn tree", "sulphur bark", "sulphur tree", "sulphur bark-thorn" or "yellow-barked *Acacia*" (Palmer & Pitman 1972, Timberlake *et al.* 1999, Hankey & Stern 2002, Palgrave 2002). The common name "fever tree" is an old name, given because the tree grows where malaria is prevalent. *Vachellia xanthophloea* was traditionally associated with malaria and early pioneers and ethnobotanists were convinced that the species was the cause of fever and malaria, and local people believing that the tree itself has the power of conveying fever and malaria (Palmer & Pitman 1972). The synonyms associated with the scientific name *V. xanthophloea* include *Acacia songwensis* Harms, *A. verrugera* auct. non Schweinf. and *A. xanthophloea* Benth. (Palmer & Pitman 1972, Hankey & Stern 2002, Kyalangalilwa *et al.* 2013).

Vachellia xanthophloea is known for the colour of its trunk, twigs and branches which are yellow-green and smooth and covered with a powdery bloom (Figure 1A). *Vachellia xanthophloea* is a semi-deciduous to deciduous small to medium-sized, single-stemmed and high branching tree. The species grows to about 30 m in height with a tall, straight and not particularly tapering bole which grows up to 1 m in diameter (Timberlake *et al.* 1999, Schmidt *et al.* 2017). The bark is smooth, greenish yellow to yellow in colour, powdery, slightly flaking or peeling off in huge thick pieces and leaving sculptured patterns on the trunk (Palgrave 2002). The crown is flattish, horizontally spreading, umbrella-shaped, sparse and mostly roundish crown with deciduous foliage. The thorns are long, straight, white, paired, often slender (Figure 1B) and sometimes underdeveloped or absent (Van Wyk 2008). The foliage has feathery leaves with a hairy midrib and fall off the branches fairly early. The sweetly scented flowers are in round, golden balls on slender stalks, white or yellowish-white in colour and borne together with a tuft of leaves in the axils of the thorns (Figure 1C). The pods are pale brown, more or less straight, flat, slightly constricted between seeds, rather papery, thin-textured, obscurely reticulate and usually borne in small clusters. The pods are indehiscent and break up into segments on the ground. *Vachellia xanthophloea* is not a widely distributed species, occurring in groups in low-lying, swampy areas, near rivers, on the banks of lakes, dams, pans and areas with high groundwater tables, on alluvial black clay, black-cotton soils at an altitude ranging from 25 m to 2000 m above sea level (Timberlake *et al.* 1999, Germishuizen & Meyer 2003, Dharani 2019). *Vachellia xanthophloea* has been recorded in bushveld, depressions and forming dense stands in seasonally flooded areas (Venter & Venter 2015). *Vachellia xanthophloea* is native to tropical and subtropical climates, recorded in southern and eastern Africa in countries such as Botswana, the Democratic Republic of Congo (DRC), Eswatini, Kenya, Malawi, Mozambique, Somalia, South Africa, Tanzania, Zambia and Zimbabwe (Timberlake *et al.* 1999, Palgrave 2002, Germishuizen & Meyer 2003, Dharani 2019).

Medicinal uses of *Vachellia xanthophloea*

The gathering and trading of *V. xanthophloea* parts as sources of traditional medicines entered the informal commercial sectors of the tropical African economy more than 50 years ago (Cunningham 1993, Mander 1998, Dold & Cocks 2002, Mankga *et al.* 2013). In southern Africa, *V. xanthophloea* is regarded as an important source of traditional medicines in the region, and therefore, the species is included in two monographs "Zulu medicinal plants: An inventory" (Hutchings *et al.* 1996) and "Medicinal and magical plants of southern Africa: An annotated checklist" (Arnold *et al.* 2002), emphasizing the botanical description, parts used, medicinal uses, preparation and dosage, active ingredients and pharmacological effects of the species. A patent emphasizing the methods of extraction and isolation of an alkaloid-containing aqueous extract of V. *xanthophloea* was registered about five years ago (Meacock *et al.* 2017). Therefore, this intensive gathering of *V. xanthophloea* from the wild for its bark, roots and stems poses a serious threat to the survival of the species, thereby increasing its risk of extinction and leading to scarcity of the species due to over-harvesting in the wild (Mander 1998, Grace *et al.* 2003a). Research conducted about 30 years ago in South Africa showed that *V. xanthophloea* was one of the species becoming increasingly scarce as a source of traditional medicines in the country (Mander 1998, Grace *et al.* 2003a). Although *V. xanthophloea* is considered as a species of conservation concern throughout its distributional range due to lack of young plants (Timberlake *et al.* 1999, Dharani *et al.* 2006, White *et al.* 2019). But in South Africa, *V. xanthophloea* does not seem to be in immediate danger of extinction as the species is widespread, recorded in a wide range of habitats and characterized by a large population size (Raimondo *et al.* 2009). But from a sustainability perspective, there is need to preserve the genetic diversity of *V. xanthophloea* and monitor its population given continuing habitat decline and fragmented population throughout its distributional range. Research conducted by Dharani *et al.* (2006) and White *et al.* (2019) reported losses of *V. xanthophloea* woodlands along the riparian areas throughout eastern and southern Africa, and such results imply that decreasing population size of the species is likely to result in the loss of important terrestrial and aquatic ecosystem services associated with the species.

The bark, roots and stems of *V. xanthophloea* are widely sold as sources of traditional medicines in informal herbal medicine markets in Eswatini, Kenya, South Africa and Tanzania (Cunningham 1993, Mander 1998, Williams *et al.* 2000, 2001, 2007, 2014, Dold & Cocks 2002, Botha *et al.* 2001, 2002, 2007, Grace *et al.* 2002, 2003b, Mankga *et al.* 2013, Nahashon 2013, Mwaura *et al.* 2020, Mbongwa *et al.* 2021). The bark of *V. xanthophloea* is one of the most commonly stocked herbal medicine products in the informal herbal medicine markets in South Africa (Mander 1998, Williams *et al.* 2000, 2001, 2007, 2014, Botha *et al.* 2002, 2007, Grace *et al.* 2002, 2003b) and Grace *et al.* (2003a) tried to authenticate dried bark of the species using thin layer chromatography (TLC). This study showed that the dried bark of V. *xanthophloea* is often confused with dried bark of *Croton sylvaticus Hochst.* ex C. Krauss (family Euphorbiaceae), *Albizia adianthifolia* (Schumach.) W.F.Wight and *Vachellia sieberiana* (DC.) Kyal. & Boatwr. (family Fabaceae), and these three plant species are sold as herbal medicines in the informal herbal medicine markets in South Africa (Maroyi 2017, 2018). Grace *et al.* (2003a) argued that the notable similarities in the phytochemical fingerprints of *A. adianthifolia, C. sylvaticus, V. sieberiana* and *V. xanthophloea* may be an indicator of close usage relationships as the bark products are often purposefully substituted for one another (Grace *et al.* 2003a, Maroyi 2017, 2018).

In traditional medicine, the bark, leaves, roots, root bark, stems and stem bark of *V. xanthophloea* have medicinal value and are also used for magical or ritual purposes (Tables 1). The medicinal use categories include the mono and multi-therapeutic applications of the species against both human and animal ailments and diseases (Tables 1). The medicinal uses of *V. xanthophloea* have been recorded in Eswatini, Kenya, South Africa and Tanzania, representing 36.4% of the countries where *V. xanthophloea* is indigenous. Most of the ethnobotanical data on medicinal applications of *V. xanthophloea* have been reported in Kenya and South Africa, supported by 14 and 17 literature sources, respectively (Figure 2). *Vachellia xanthophloea* is used in different combinations with other medicinal plants in Kenya and South Africa to treat and manage several human diseases or ailments (Table 1), and therefore, further ethnopharmacological research is required to assess possible synergistic effects of *V. xanthophloea* when used in combination with other medicinal plant species.

Table 1. Medicinal uses of *Vachellia xanthophloea*

Medicinal applications	Parts used	Country	Reference
Mono-therapeutic applications			
Abdominal pains	Root decoctions	South Africa	Watt & Breyer-Brandwijk 1962, Hutchings *et al.* 1996
Appetizer	Bark or root decoction taken orally	Kenya	Kiringe 2006, Mutie *et al.* 2023
Blood purification	Bark decoction administered as enema	South Africa	Hutchings *et al.* 1996, Zwane *et al.* 2024
Cathartic	Root decoction taken orally	Tanzania	Johns *et al.* 1994
Colds	Bark or root decoction taken orally	Kenya	Mutie *et al.* 2023
Constipation	Bark or root decoction taken orally	Kenya	Mutie *et al.* 2023
Cough	Bark or root decoction taken orally	Kenya	Dharani 2019, Mutie *et al.* 2023
Diarrhea	Bark or root decoction taken orally	Kenya	Tsigemelak *et al.* 2016, Mutie *et al.* 2023
Emetic	Powdered bark of the stem or root taken orally as a decoction	South Africa and Tanzania	Watt & Breyer-Brandwijk 1962, Johns *et al.* 1994, Hutchings *et al.* 1996, Grace *et al.* 2003b, Cumes *et al.* 2009, Orwa *et al.* 2009, Schmidt *et al.* 2017, Zwane *et al.* 2024
Eye problems	Bark decoction applied topically	South Africa	Hankey & Stern 2002, Lemmens 2008, Thomas & Grant 2013

Fatigue	Root or stem bark decoction taken orally	Kenya and South Africa	Hutchings 1989, Muthee *et al.* 2011, Mutie *et al.* 2023
Fever	Bark decoction taken orally	South Africa	Hankey & Stern 2002, Thomas & Grant 2013, Zwane *et al.* 2024
Good luck or love charm	Bark decoction	South Africa	Hutchings *et al.* 1996, Grace *et al.* 2003b, Corrigan *et al.* 2011, Schmidt *et al.* 2017, Zwane *et al.* 2024
Indigestion	Bark or root decoction taken orally	Kenya	Lemmens 2008, Mutie *et al.* 2023
Joint pains	Bark decoction applied topically	Kenya	Ratemo *et al.* 2020
Magical purposes	Bark infusion	Eswatini and South Africa	Dlamini 1981, Pooley 1993, 1998, Hutchings *et al.* 1996, Grace *et al.* 2003b, Corrigan *et al.* 2011
Malaria	Powdered bark of the roots or stems taken orally as decoction	Kenya, South Africa and Tanzania	Watt & Breyer-Brandwijk 1962, Chhabra *et al.* 1984, Hutchings *et al.* 1996, Grace *et al.* 2003b, Lemmens 2008, Cumes *et al.* 2009, Nahashon 2013, Schmidt *et al.* 2017, Mutie *et al.* 2023
Oedema	Bark decoction taken orally	Kenya	Wanzala *et al.* 2016
Pneumonia	Leaf, root or stem infusion taken orally	Kenya	Kiringe 2006, Nyang'au *et al.* 2017, Mutie *et al.* 2023
Prophylactic on entering malaria area	Powdered bark of the stem and root taken orally as a decoction	South Africa	Watt & Breyer-Brandwijk 1962, Hutchings *et al.* 1996, Grace *et al.* 2003b, Cumes *et al.* 2009, Orwa *et al.* 2009, Schmidt *et al.* 2017
Receding gums	Bark or root infusion taken orally	Kenya	Mutie *et al.* 2023
Sickle cell anaemia	Bark decoction taken orally	Tanzania	Chhabra *et al.* 1984, Hutchings *et al.* 1996, Lemmens 2008
Skin disorders	Bark, root or stem bark decoction applied topically	Kenya	Muthee *et al.* 2011, Mutie *et al.* 2023
Sore throat	Bark or root decoction taken orally	Kenya	Dharani 2019, Mutie *et al.* 2023
Stomach problems	Bark or root decoction taken orally	Kenya and Tanzania	Nahashon 2013, Ratemo *et al.* 2020, Mutie *et al.* 2023
Teeth cleaning as toothbrush	Stems	Kenya	Ngari *et al.* 2014
Tonsilitis	Root decoction taken orally	Tanzania	Augustino & Gillah 2005

Tuberculosis	Bark decoction taken orally	South Africa	McGaw et al. 2008, Cock & Van Vuuren 2020
Typhoid	Bark or root decoction taken orally	Kenya	Mutie *et al.* 2023
Ethnoveterinary medicine			
Coccidiosis (coccidia) and colibacillosis for calves, goat kids and lambs	Bark	Kenya	Dharani *et al.* 2015
Cough	Bark, root or stem bark infusion	Kenya	Kama-Kama *et al.* 2016, Mutie *et al.* 2023
Foot and mouth disease	Bark	Kenya	Gakuubi & Wanzala 2012, Mutie *et al.* 2023
Gastrointestinal nematodes in goats	Bark or leaves	South Africa	Ndlela *et al.* 2022
Multi-therapeutic applications			
Amoebiasis	Bark mixed with that of *Leucas calostachys* Oliv. (Lamiaceae family) and *Maerua decumbens* (Brongn.) DeWolf (Capparaceae family), leaves of *Bersama abyssinica* Fresen. (Francoaceae family), roots of *Terminalia brownii* Fresen. (Combretaceae family) and *Vepris nobilis* (Delile) Mziray (Rutaceae family)	Kenya	Kigen *et al.* 2014, Mutie *et al.* 2023
Arthritis	Roots mixed with those of *L. calostachys*, *Olea europaea* L. (Oleaceae family), *T. brownii* and *Zanthoxylum asiaticum* (L.) Appelhans (Rutaceae family)	Kenya	Kigen *et al.* 2014, Mutie *et al.* 2023
Cancer	Bark mixed with that of *Ficus thonningii* Blume (Moraceae family), *Olea europaea* L. subsp. *africana* (Mill.) P.S.Green (Oleaceae family) and *T. brownii*	Kenya	Kigen *et al.* 2014, Mutie *et al.* 2023
Cleansing stomach	Bark mixed with roots of *Capparis tomentosa* Lam. (Capparaceae family) and *Hermbstaedtia odorata* (Burch.) T.Cooke var. *odorata* (Amaranthaceae family)	South Africa	Watt & Breyer-Brandwijk 1962, Hutchings *et al.* 1996
Hypertension	Bark mixed with that of *Albizia amara* (Roxb.) Boivin (Fabaceae family), *Carissa spinarum* L. (Apocynaceae family), *Combretum apiculatum* Sond. (Combretaceae family), *Erythrina abyssinica* Lam. (Fabaceae family), *Flacourtia indica* (Burm.f.) Merr. (Salicaceae family) and *Prunus africana* (Hook.f.) Kalkman (Rosaceae family)	Kenya	Kigen *et al.* 2014, Mutie *et al.* 2023
Infertility in women	Bark mixed with tubers of *Cucumis prophetarum* L. (Cucurbitaceae family) and roots of *C. spinarum* and *Rhoicissus tridentata* (L.f.) Wild & R.B.Drumm. (Vitaceae family)	Kenya	Kigen *et al.* 2014, Mutie *et al.* 2023
Love charm	Bark mixed with whole plant of *Lithops lesliei* (N.E.Br.) N.E.Br. (Aizoaceae family)	South Africa	Smith & Crouch 1999
Mumps	Bark mixed with that of *E. abyssinica*	Kenya	Kigen *et al.* 2014, Mutie *et al.* 2023

Peptic ulcers	Bark mixed with that of *A. amara* and *P. africana*, roots of *C. spinarum*, *E. abyssinica* and *L. calostachys* and tuber of *R. tridentata*	Kenya	Kigen *et al.* 2014, Mutie *et al.* 2023
Renal disorders	Bark mixed with tubers of *R. tridentata*, roots of *L. calostachys*, Rhamnus prinoides L'Hér., *Trimeria grandifolia* (Hochst.) Warb. (Salicaceae family) and *Z. asiaticum*	Kenya	Kigen *et al.* 2014, Mutie *et al.* 2023

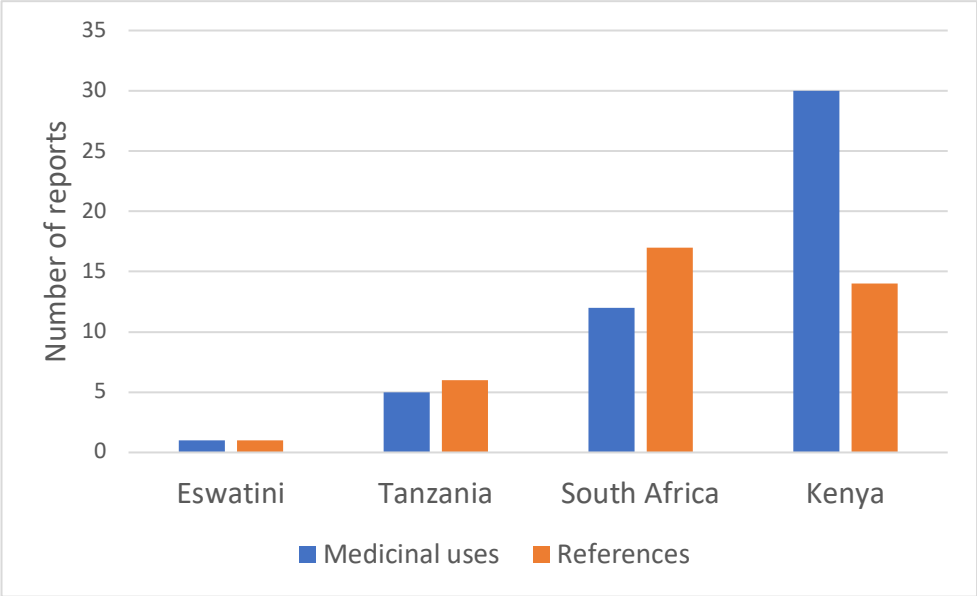

Figure 2. Medicinal uses of *Vachellia xanthophloea* and number of literature sources

Phytochemical composition and pharmacological properties of *Vachellia xanthophloea*

The leaves, stem bark and charcoal of *V. xanthophloea* contain alcohols, aldehydes, alkanes, alkenes, benzene derivatives, carboxylic acids, esters, flavonoids, ketones, phenols, phthalates, polycyclic aromatic hydrocarbons, triterpenoids and volatile oils (Table 2). Some of these phytochemical compounds isolated from *V. xanthophloea* exhibited antiplasmodial activities on their own and some in various mixtures. Perhaps more research is required as some of these phytochemical compounds may be responsible for the biological activities associated with the species which include anthelmintic, antibacterial, antimycobacterial, antifungal, anti-asthmatic, anti-inflammatory, antioxidant, antiplasmodial and $GABA_A$-benzodiazepine receptor-binding activities.

Table 2. Phytochemical composition of *Vachellia xanthophloea*

Phyotochemical compound	**Formula**	**Plant part**	**Reference**
1-heptacosanol	$C_{27}H_{56}O$	Leaves	Tajuddeen *et al.* 2022
1-Methylnaphthalene	$C_{11}H_{10}$	Charcoal	Shikorire *et al.* 2019
1,4-Dimethylnaphthalene	$C_{12}H_{12}$	Charcoal	Shikorire *et al.* 2019
1,5-Dimethyl-1,2,3,4-tetrahydronaphthalene	$C_{12}H_{16}$	Charcoal	Shikorire *et al.* 2019
2'-hydroxy-3,7,8,4'5'-pentamethoxyflavone 2	$C_{20}H_{20}O_8$	Leaves	Tajuddeen *et al.* 2022
2,6-Diisopropylnaphthalene	$C_{16}H_{20}$	Charcoal	Shikorire *et al.* 2019
2,7-Dimethylnaphthalene	$C_{12}H_{12}$	Charcoal	Shikorire *et al.* 2019
3-O-methylquercetin	$C_{16}H_{12}O_7$	Leaves	Tajuddeen *et al.* 2022
3,7,8,2',4',5'-hexamethoxyflavone 1	$C_{21}H_{22}O_8$	Leaves	Tajuddeen et al. 2022
5-O-Caffeoylquinic acid	$C_{16}H_{17}O_9$	Leaves	Elshamy *et al.* 2024
5,7,2'-trihydroxy-3,4',5'-trimethoxyflavone	$C_{18}H_{16}O_8$	Leaves	Tajuddeen *et al.* 2022
Anthracene	$C_{14}H_{10}$	Charcoal	Shikorire *et al.* 2019
Apigenin	$C_{15}H_{10}O_5$	Leaves	Tajuddeen *et al.* 2022
Apigenin glucoside	$C_{21}H_{20}O_{10}$	Leaves	Elshamy *et al.* 2024

Baicalein	$C_{15}H_{10}O_5$	Leaves	More *et al.* 2021a
Bis(2-ethylhexyl) terephthalate	$C_{24}H_{39}O_4$	Stem bark	Cheloti *et al.* 2023b
Caffeic acid	$C_9H_8O_4$	Leaves	More *et al.* 2021a
Caffeic acid-O-hexoside	$C_{15}H_{17}O_9$	Leaves	Elshamy *et al.* 2024
Catechin	$C_{15}H_{13}O_6$	Leaves	Tajuddeen *et al.* 2022, Elshamy *et al.* 2024
Catechin-5,7-digallate	$C_{29}H_{21}O_{14}$	Leaves	Elshamy *et al.* 2024
Catechin-7-O-gallate	$C_{22}H_{17}O_{10}$	Leaves	Elshamy *et al.* 2024
Chlorogenic acid	$C_{16}H_{18}O_9$	Leaves	Elshamy *et al.* 2024
Chrysoeriol glucopyranoside	$C_{22}H_{22}O_{11}$	Leaves	More *et al.* 2021a
Cyanidin rhamnoside	$C_{21}H_{20}O_{10}$	Leaves	More *et al.* 2021a
Dihydroacacipetalin	$C_{11}H_{19}NO_6$	Leaves	More *et al.* 2021a
Dihydroquercetin	$C_{15}H_{12}O_7$	Leaves	Tajuddeen *et al.* 2022
E-lutein	$C_{40}H_{56}O_2$	Leaves	Tajuddeen *et al.* 2022
Epigallocatechin	$C_{15}H_{14}O_7$	Leaves	More *et al.* 2021a,b, Elshamy *et al.* 2024
Epigallocatechin gallate	$C_{22}H_{18}O_{11}$	Leaves	More *et al.* 2021a, Elshamy *et al.* 2024
Fluorene	$C_{13}H_{10}$	Charcoal	Shikorire *et al.* 2019
Gallic acid	$C_7H_6O_5$	Leaves	More *et al.* 2021a, Elshamy *et al.* 2024
Gallocatechin	$C_{15}H_{14}O_7$	Leaves	Tajuddeen *et al.* 2022
Hyperoside	$C_{21}H_{20}O_{12}$	Leaves	Elshamy *et al.* 2024
Isorhamnetin-3-O-rhamnosyl-rutinoside	$C_{34}H_{41}O_{20}$	Leaves	Elshamy *et al.* 2024
Kaempferol	$C_{15}H_{10}O_6$	Leaves	More *et al.* 2021a, Tajuddeen *et al.* 2022, Elshamy *et al.* 2024
Kaempferol-3-O-glucoside	$C_{21}H_{19}O_{11}$	Leaves	Elshamy *et al.* 2024
Kaempferol 3-O-rhamnosylrutinoside	$C_{33}H_{40}O_{19}$	Leaves	Elshamy *et al.* 2024
Kaempferol-3-O-rutinoside	$C_{27}H_{29}O_{15}$	Leaves	Elshamy *et al.* 2024
Kaempferol rutinoside	$C_{27}H_{30}O_{15}$	Leaves	Elshamy *et al.* 2024
Lupeol	$C_{30}H_{50}O$	Leaves	Tajuddeen *et al*. 2022
Luteolin glucoside	$C_{21}H_{20}O_{11}$	Leaves	More *et al.* 2021a, Elshamy *et al.* 2024
Methyl gallate	$C_8H_8O_5$	Leaves	More *et al.* 2021a,b, Tajuddeen *et al.* 2022
Myricetin rutinoside	$C_{27}H_{30}O_{17}$	Leaves	More *et al.* 2021a
Naphthalene	$C_{10}H_8$	Charcoal	Shikorire *et al.* 2019
p-coumaric acid-O-hexoside	$C_{15}H_{17}O_8$	Leaves	Elshamy *et al.* 2024
Pinoresinol	$C_{20}H_{22}O_6$	Leaves	Tajuddeen *et al.* 2022
Phytol	$C_{20}H_{40}O$	Leaves	Tajuddeen *et al.* 2022
Protocatechuic acid pentosyl hexoside	$C_{18}H_{23}O_{13}$	Leaves	Elshamy *et al.* 2024
Pyrene	$C_{16}H_{10}$	Charcoal	Shikorire *et al.* 2019
Quercetin	$C_{15}H_{10}O_7$	Leaves	More *et al.* 2021a,b, Tajuddeen *et al.* 2022, Elshamy *et al.* 2024
Quercetin-3-O-dihexoside	$C_{27}H_{29}O_{17}$	Leaves	Elshamy *et al.* 2024
Quercetin-3-O-glucoside	$C_{21}H_{19}O_{12}$	Leaves	Elshamy *et al.* 2024
Quercetin-3-O-rhamninoside	$C_{33}H_{39}O_{20}$	Leaves	Elshamy *et al.* 2024
Quercetin rutinoside	$C_{27}H_{30}O_{16}$	Leaves	More *et al.* 2021b
Quinic acid	$C_7H_{12}O_6$	Leaves	Elshamy *et al.* 2024
Rutin	$C_{27}H_{29}O_{16}$	Leaves	Elshamy *et al.* 2024
Salicylic acid-O-hexoside	$C_{13}H_{15}O_8$	Leaves	Elshamy *et al.* 2024
tri-O-methylgallic acid	$C_{10}H_{12}O_5$	Leaves	Van Heerden & Tajuddeen 2019
Vanilllic acid-O-hexoside	$C_{14}H_{17}O_9$	Leaves	Elshamy *et al.* 2024

Vitexin 2”-O-gallate	$C_{28}H_{23}O_{14}$	Leaves	Elshamy *et al.* 2024
Vitexin digallate	$C_{35}H_{27}O_{18}$	Leaves	Elshamy *et al.* 2024
Vitexin 2”-O-(E)-ferulate	$C_{31}H_{27}O_{13}$	Leaves	Elshamy *et al.* 2024
Vitexin-O-galloyl-deoxyhexoside	$C_{37}H_{29}O_{16}$	Leaves	Elshamy *et al.* 2024

Anthelmintic activities

Ndlela *et al.* (2021) evaluated the anthelmintic activities of aqueous and methanolic extracts of *V. xanthophloea* bark against pooled sample of gastrointestinal nematodes, that is, *Haemonchus* (64.0%), *Oesophagostomum* (23.0%) and *Trichostrongylus* (13.0%). The extracts exhibited a linear relationship between larvae mortality of L3 nematodes and concentration of the extracts (Ndlela *et al.* 2021).

Antibacterial activities

Katerere & Eloff (2004) evaluated the antibacterial activities of acetone and chloroform extracts of V. *xanthophloea* leaves against *Staphylococcus aureus* and *Escherichia coli* using the serial dilution microtitre method with ampicillin and neomycin as positive controls. The extracts exhibited activities against the tested pathogens with minimum inhibitory concentration (MIC) values ranging from 0.08 mg/ml to 5.0 mg/ml (Katerere & Eloff 2004). Erhabor *et al.* (2022) evaluated the antibacterial activities of acetone and methanol extracts of V. xanthophloea leaves against *Salmonella typhimurium, Salmonella enteritidis, Escherichia coli, Staphylococcus aureus, Campylobacter jejuni, Stenotrophomonas maltophilia, Klebsiella pneumoniae* and *Enterobacter cloacae* using the serial microdilution method with gentamicin as a positive control. The extracts exhibited activities against the tested pathogens with MIC values ranging from <0.02 mg/ml to 0.84 mg/ml (Erhabor *et al.* 2022).

Antimycobacterial activities

Lall & Meyer (1999) evaluated the antimycobacterial activities of acetone extracts of *V. xanthophloea* bark against drug-resistant (CCKO28469V) and drug-sensitive strains (H37Rv) of *Mycobacterium tuberculosis* using the agar plate and rapid radiometric methods with streptomycin, isoniazid, ethambutol and rifampin as positive control. The extract exhibited activities against the tested pathogens with MIC value of 0.5 mg/ml (Lall & Meyer 1999).

Antifungal activities

More *et al.* (2021b) evaluated the antifungal activities of aqueous : methanol (1 : 1) extract of *V. xanthophloea* leaves against *Candida auris, Candida glabrata, Candida parapsilosis* and *Candida tropicalis* using the broth microdilution method with amphotericin B as a positive control. The extract exhibited activities against the tested pathogens with MIC values ranging from 0.2 mg/ml to 0.6 mg/ml (More *et al.* 2021b).

Anti-asthmatic activities

Odongo *et al.* (2015) evaluated the anti-asthmatic activities of aqueous and methanol extracts of V. *xanthophloea* leaves in concentrations of 50.0, 100.0 and 200.0 mg/kg body weight on asthma induced female Swiss Albino mice by using 1.0% ovalbumin. The extracts exhibited activities by reducing the serum total immunoglobin E levels by at least 90.0% (Odongo *et al.* 2015).

Anti-inflammatory activities

More *et al.* (2021b) evaluated the anti-inflammatory activities of aqueous : methanolic (1 : 1) extract of *V. xanthophloea* leaves using the 2’,7’-dichlorofluorescin diacetate (H2DCF-DA) method. The extract decreased reactive oxygen species (ROS) by 49.0%, highlighting the anti-inflammatory potential of the species (More *et al.* 2021b).

Antioxidant activities

More *et al.* (2021a) evaluated the antioxidant activities of aqueous : methanolic (1 : 1) extract of *V. xanthophloea* leaves using the 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid (ABTS), 2,2-di-phenyl-1-picrylhydrazyl (DPPH) free radical scavenging and the ferric reducing antioxidant power (FRAP) assays with ascorbic acid as positive control. The extract exhibited activities against ABTS, DPPH and FRAP with half maximal inhibitory concentration (IC_{50}) values ranging from 3.61 µg/ml to 23.20 µg/ml (More *et al.* 2021a). Erhabor *et al.* (2022) evaluated the antioxidant activities of acetone and methanol extracts of *V. xanthophloea* leaves using the ABTS and DPPH free radical scavenging assays with trolox and vitamin C as positive controls. The extracts exhibited activities with IC_{50} values ranging from 0.14 µg/ml to 2.83 µg/ml (Erhabor *et al.* 2022). Elshamy *et al.* (2024) evaluated the antioxidant activities of methanol extracts of *V. xanthophloea* leaves using the

ABTS and DPPH free radical scavenging assays with trolox as a positive control. The extract exhibited activities with IC_{50} values ranging of 0.4 mg/ml and 1.0 mg/ml against ABTS and DPPH, respectively (Elshamy *et al.* 2024).

Antiplasmodial activities

Prozesky *et al.* (2001) evaluated the antiplasmodial activities of acetone extract of *V. xanthophloea* stem bark against a chloroquine resistant strain (PfUP1) of *Plasmodium falciparum* by means of the flow cytometric test with chloroquine as a positive control. The extract demonstrated activities by exhibiting IC_{50} value of 10.1 µg/ml (Prozesky *et al.* 2001). Muthaura *et al.* (2015) evaluated the antiplasmodial activities of methanol extracts of *V. xanthophloea* stem bark against chloroquine resistant (W2) *Plasmodium falciparum* using the semi-automated micro-dilution technique that measures the ability of the extracts to inhibit the incorporation of (G^3-H) hypoxanthine into the malaria parasite. The extract exhibited activities with IC_{50} values of 17.3 µg/ml (Muthaura *et al.* 2015). Tajuddeen *et al.* (2022) evaluated the antiplasmodial activities of ethyl acetate extract of *V. xanthophloea* leaves against *Plasmodium falciparum* 3D7 clone using a parasite lactate dehydrogenase assay with chloroquine as a positive control. The extract exhibited activities with IC_{50} value of 10.6 µg/ml (Tajuddeen *et al.* 2022). Tajuddeen *et al.* (2022) also evaluated the antiplasmodial activities of the phytochemical compounds dihydroquercetin, methyl gallate, kaempferol, mixture (1 : 1) of 3-O-methylquercetin and methyl gallate isolated from *V. xanthophloea* leaves using a parasite lactate dehydrogenase assay with chloroquine as a positive control. The phytochemical compounds exhibited activities with IC_{50} values ranging from 1.2 µg/ml to 27.6 µg/ml (Tajuddeen *et al.* 2022). Christopher *et al.* (2023) evaluated the antiplasmodial activities of ethanol extracts of *V. xanthophloea* leaves, root bark and stem bark against chloroquine-sensitive (3D7) and multidrug-resistant (Dd2) strains of *Plasmodium falciparum* using a SYBR green I-based fluorescence assay with artemisinin and chloroquine as positive controls. The extracts exhibited activities against the tested pathogens with IC_{50} values ranging from 13.3 µg/ml to 27.4 µg/ml (Christopher *et al.* 2023).

$GABA_A$-benzodiazepine receptor-binding activities

Stafford *et al.* (2005) evaluated the $GABA_A$-benzodiazepine receptor-binding activities of ethanol extracts of *V. xanthophloea* leaves using the $GABA_A$-benzodiazepine receptor-binding assay. The extract exhibited dose-dependent moderate activities (Stafford *et al.* 2005).

Conclusion

The present review provides a summary of the botanical information, traditional uses and ethnopharmacological properties of *V. xanthophloea*. *Vachellia xanthophloea* is a valuable natural resource in eastern and southern Africa characterized by numerous medicinal, traditional and cultural uses throughout its distributional range. However, detailed studies focusing on phytochemical and pharmacological properties, toxicity and safety, mechanisms of action *in vivo,* and clinical research aimed at corroborating the traditional medicinal applications of the species are required. It is also surprising that there are no ethnopharmacological studies examining the combinational effects of *V. xanthophloea* extracts with other plant species. Whilst the field of synergistic combinational therapy is still in its infancy, more research is required to test *V. xanthophloea* extracts in combination with extracts of plant species such as *A. amara, B. abyssinica, C. prophetarum, C. spinarum, C. tomentosa, E. abyssinica, F. thonningii, H. odorata* var. *odorata, L. calostachys, L. lesliei, M. decumbens*, *O. europaea, O. europaea* subsp. *africana, P. africana,* R. prinoides, *R. tridentata*, *T. grandifolia, T. brownii, V. nobilis* and *Z. asiaticum.*

Declarations

List of abbreviations: ABTS - 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid; DPPH - 2,2-di-phenyl-1-picrylhydrazyl; FRAP - free radical scavenging and the ferric reducing antioxidant power; MIC - minimum inhibitory concentration; ROS - reactive oxygen species; TLC - thin layer chromatography

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