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Eco-luxury: Making sustainable drugs and cosmetics with *Prosopis cineraria* natural extracts

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Climate change associated with global warming is a major warning of the twenty-first century, threatening ecosystems through uncontrolled temperature rises, drought, lack of water with a strong impact on productivity, economy, and worldwide life well-being. In most cases, the poor regions of the planet suffer from a lack of exploitable resources deriving from natural reserves. For this reason, wild vegetables able to grow in deserted areas are attracting increasing attention due to their beneficial properties. Among them, *Prosopis cineraria* has been recently recognized in the UAE not only as a cultural heritage but also as a potential source of raw materials for agri-food and pharmaceutics still poorly valued. *P. cineraria* occurs in most of the world's hot arid and semi-arid regions as a native or introduced species and, due to its multiple properties, could be exploited for medical, food, and, more recently, in different growing productivity fields like a luxury, especially in countries like the UAE. The use of actives-rich natural sources offers clear advantages over synthetic compounds in terms of process and product eco-sustainability. In this manuscript, we review the main properties and potential applications of *P. cineraria* aiming to promote the scientific interest toward the development of innovative approaches in several productive fields, including pharma and cosmetics, exploiting the versatility of materials that can be extracted from the various parts of the plant and discuss commercialization opportunities of the plant to support biodiversity and sustainability. In conclusion, *P. cineraria* turns out to be a plant able to grow in hostile environments, already providing nutrients for populations of Western Asia and the Indian subcontinent and possibly translatable to poor arid regions.

KEYWORDS

***Prosopis cineraria*, eco-sustainability, arid regions, agrofood, cosmetics, pharmaceutics, natural products**

Introduction

In 1999, United Arab Emirates (UAE) became a member of the United Nations Convention to Combat Desertification (UNCCD), with a National Environmental Strategy to demonstrate its commitment to this convention (Al-Yamani et al., 2019). As one of the native trees of UAE that is a true survivor in the face of fiery temperatures, searing winds, and harsh desert conditions, in 2008, the Ghaf tree (i.e., *Prosopis cineraria*) has been declared the national tree of the UAE, and as a historical and cultural symbol, in 2019 it was used as the symbol of year of tolerance, representing the stability and peace in the UAE's desert environment (Jongbloed et al., 2003; EAD, 2019). Nowadays, *P. cineraria* occurs in most of the world's hot arid and semi-arid regions as a native or introduced species (Pasiecznik et al., 2001). Historically, the Ghaf tree has been integrated into many ways to traditional lifestyles in Asian countries as a natural remedy for various conditions and illnesses (Khatri et al., 2010; Janbaz et al., 2012; Afifi and Al-rub, 2018). Apart from remedial usage, the leaves and pods of the Ghaf tree are used for traditional cooking, and as fodder, its flowers are found good source for honey production while the canopy of the tree functions as a shelter for the wildlife and improves the micronutrients on the desert terrain (Kumar et al., 2011; Afifi and Al-rub, 2018).

The multifaceted potential of the *Prosopis* plant family

Prosopis is a genus of plant that belongs to the family Fabaceae (Leguminosae) (sub. family Mimosaceae) and comprises 44 known species, three of them native to Asia, one to Africa, and the others to America (González-Montemayor et al., 2019). *Prosopis* species are one of the major sources of proteins in arid and semi-arid regions as well as a good source of carbohydrates, lipids, minerals, and phytochemical compounds with beneficial effects on health (Afifi and Al-rub, 2018). *Prosopis* pods constitute a food source for humans and animals of the Monte desert as well as they are important nutrition sources for Amerindians in the Paraguayan Chaco and Chile. Different food products are made from *Prosopis* species: drinks (añapa, aloja, and chichi), syrup, flour, and sweets (arrope, patay, and jam) (Pérez et al., 2014). The beverage known as "anapa" is produced by mixing its pods in water, while after being fermented, it produces the alcoholic beverage "chichi" (Henciya et al., 2017).

Prosopis species have been used as a folk indigenous medicine for various ailments. The barks are dry, acrid, and bitter, with a sharp taste and cure leprosy, dysentery, asthma, leukoderma, tremors of the muscle, and wandering of the mind, while its ashes are rubbed over the skin to remove hair. Besides, the pounded flowers are mixed with sugar and used during pregnancy as protection against miscarriage; the smoke of the leaves is good for eye infections, and extracts are recommended against snakebite and scorpion sting, while fresh leaves juice mixed with lemon juice is used for dyspepsia; the extract of crushed pods is used for earache, toothache, and pain relief from fractured bones; the aqueous extract of bark and leaves is used to cure mouth and throat infections, bronchitis, ulcers, internal diseases including parasites and urinary diseases as well as applied externally to treat skin disease, disinfect wounds, and promote healing (Garg and Mittal, 2013; Henciya et al., 2017). Moreover, in Argentinean traditional medicine, *Prosopis* fruit is used as a sedative, and in pathologies associated with inflammatory processes like asthma and bronchitis (Carrizo et al., 2002). Several studies supported by advanced scientific technologies have demonstrated *Prosopis* pharmacological properties, including antioxidant, hepatoprotective, hemolytic, anticancer, antibacterial, antifungal, antidiabetic, and anti-inflammatory activities (Henciya et al., 2017).

People from the United States, Mexico, Peru, Bolivia, Chile, Paraguay, and Argentina have exploited this plant for their survival also because it has important economic value as a source of fuel and fodder, in charcoal production, and as construction material (González-Montemayor et al., 2019). Since its wood is extremely hard and durable and has an attractive coloration, it is used for making furniture and parquet floors (Henciya et al., 2017). Furthermore, due to its high carbohydrate content, attention has been paid to the potential of pods as a source of biofuels by processing the carbohydrates into ethanol and preliminary tests converted up to 80% of pods carbohydrates into bioethanol (Pasiecznik et al., 2001).

Prosopis cineraria: Geographic distribution, economic, and ecological importance

Prosopis cineraria is a thorny, irregularly branched flowering evergreen tree with a small-to-moderate size, mainly found in the regions of Arabia and India (Garg and Mittal, 2013). Different names are given to the *P. cineraria*: in India is called "Khejri" or "Kalpavriksha" (Kumar et al., 2019), "Jand" in Pakistan, and "Ghaf" in Arabic (Malik et al., 2013).

As xerophyte, *P. cineraria* can grow in arid and semi-arid regions, tolerates extreme temperatures (Lee and Felker, 1992 and González-Montemayor et al., 2019) it is described as an aridity-loving tree because in drought conditions it produces more flowers and fruits. The rooting can be very deep so that the tap root can penetrate up to 35-m deep vertically. This guarantees a stable base and a supply of water from the deep layers of soil, allowing the tree to withstand the hottest winds and the long dry season. Besides, it can also tolerate frost and a temperature $<10\ ^{\circ}C$ during the winter season. The tree can grow on soils of different natures but develops better on alluvial

soils made up of various mixtures of sand and clay (Khatri et al., 2010).

Prosopis cineraria tree makes a noteworthy contribution to the farm economy and rural area development and has been appreciated for the versatility of all its parts (Afifi and Al-rub, 2018) to the point of being named "the Wonder Tree" or "the King of Desert" [United States National Academy of Sciences (USNAS), 1980] or "the Golden Tree of Indian deserts" (Liu et al., 2012). *Prosopis cineraria* is a natural source of fuel and fodder in the arid regions of India and represents a good quality wood resource for basic construction for people in desert regions. However, in the global market, this plant's economic importance remains severely limited; for this reason, it has been neglected by researchers and industry (González-Montemayor et al., 2019).

Ecologically, it has the role of preventing soil erosion and dune stabilization thanks to its deep mass root system. It is adapted to survive in highly saline and alkaline soils, and it is grown aside from the millet crop as an atmospheric nitrogen fixer (Anand et al., 2017). Moreover, Litterfall production and decomposition rate are the highest compared to other trees growing in arid climates. Farmers tend to cultivate the fields under its canopy as this increases the growth and productivity of their crops. In fact, *P. cineraria* accumulates organic matter in the soil reaching the soluble calcium and phosphorus available and reducing the pH of the soil. Also, *P. cineraria* is largely used to produce feed as the leaves and pods are eaten by camels, cattle, sheep, and goats (Afifi and Al-rub, 2018). Finally, due to its long and abundant flowering, it is one of the most important plants for bee foraging in the Persian Gulf and the honey produced is of good quality (Sajwani et al., 2014).

Medical properties

Different uses of *P. cineraria* as a traditional medicine to treat various diseases were reported. In particular, the oral or topical administration of its leaves, stems, fruits, flowers, barks, and pods is used in different regions of Pakistan for the treatment of spasms, diabetes, liver infection, diarrhea, bladder and pancreas stones, fever, flu, rheumatism, leucorrhea, boils, blisters, scorpion bite, chronic dysentery, cataract, asthma, sexually transmitted infections, and gynecological complaints. It has also been reported that the beneficial effects of this plant have been exploited in the South of Kerman in Iran as an anti-asthma and against skin rashes (Sharifi-Rad et al., 2019).

The acute and subacute toxicity of *P. cineraria* hydroalcoholic extracts from leaves (PCL) and stem bark (PCB) was evaluated in Wistar rats after ingestion both in acute and subacute modes. Extracts did not produce significant changes in behavior, breathing, cutaneous effects, sensory nervous system responses, and gastrointestinal effects in rats and no mortality occurred in acute toxicity studies (Robertson et al., 2012). The toxicity profile parameters were studied and revealed that the administration of *P. cineraria* bark produced no adverse effects on general behavior and metabolism (Purohit and Ram, 2012). Many *in vitro* and *in vivo* biological activities were attributed to *P. cineraria*, and a wide variety of preclinical studies were carried out using this plant. The main pharmacological activities and relevant medical applications are summarized in Table 1.

Toward eco-sustainable luxury products

In recent years, consumer demand for utilizing natural botanical sources in cosmetics has grown substantially due to fewer side effects, high efficiency, and easy availability (Ng et al., 2022). Therefore, research shifted toward natural products with the difficult attempt to formulate stable topical emulsions containing natural bioactive constituents. The instability of the preparation is one of the reasons why the cosmetic properties of *P. cineraria* such as skincare and anti-age have been poorly studied. An attempt was made by Mohammad et al. (2015) to formulate stable W/O emulsion cream loaded with a 2% preconcentrated *P. cineraria* extract. The cream's cosmetic potential was compared to the base (without extract) through its application to healthy human volunteers. The results showed that the formulation cream was stable, preventing color change, liquefaction, and phase separation, and the pH of the cream was in accordance with the normal skin pH range. Therefore, according to the results obtained by the panel test, it was clear that the formulation cream had optimal characteristics to be used cosmetically. However, further *in vivo* research was needed to investigate its cosmetic effects on human skin. Therefore, again Mohammad et al. (2018) investigated the emulsion *in vivo* by using a non-invasive probe cutometer and elastomer. The results displayed that this formulation (size 3 μm) decreased the skin melanin, erythema, and sebum contents up to 2.1–2.7 and 79% while increasing the skin hydration and elasticity up to two-folds and 22% as compared to the base formulation, respectively. Owing to enhanced therapeutic activity, the phytocosmetic formulation proved to be a potential skin whitening, moisturizer, anti-acne, anti-wrinkle, and anti-aging therapy and could actively induce skin rejuvenation and resurfacing.

An attempt to formulate an herbal depilatory cream containing leaves of *P. cineraria* was made by Verma et al. (2011). Leaves of *P. cineraria* and some other medicinal plants were added together with common ingredients of a cream base, i.e., calcium carbonate, cetyl alcohol, calcium hydroxide, liquid paraffin, water, and perfume. The depilatory activity was evaluated using mice. The hair growth inhibition test displayed that the effects of depilatory cream (typically over 3 weeks) gave unequivocal evidence of depilation: regrowth began on the ventral body surface 14–15 days after the last dose of depilatory

TABLE 1 *Prosopis cineraria* main medical applications.

Plant part	Solvent used for extraction	Biological activity	Target pathology/disease	Experimental model	Extract administration	Effects	References
Leaves	Ethanol	Prevention of herbicide toxicity	Paraquat-induced toxicity	Prepubertal (4 weeks old and 20–24 g) male Swiss albino mice with paraquat exposure	125–600 mg/kg b.w. (higher dose) p.o. per day for 21 days, 2 h before paraquat exposure	Moderate increased cognition and memory (Y-maze test) Decreased the latency time, increased motor activity, numbers of grooming, and rearing, and increased the crossing of peripheral lines (open field test) Reduced anxiety (EPMT test) Increased levels of dopamine and noradrenaline in the brain Alleviated paraquat-induced damages in brain, liver, kidney, and hearth through the reduction of oxidative stress by increasing the level of glutathione and superoxide dismutase and by reducing malondialdehyde	Akhtar et al., 2022
Stem bark	Methanol and water	Antivenom	Venom toxicity of the Indian cobra Naja naja	Swiss albino mice with average weight of 31 g with Intraperitoneal (i.p.) injection of saline containing $3LD_{50}$ of the crude venom	Pre-incubation with 14 mg/kg b.w.	Methanol and aqueous extract resulted in complete life protections for 1 and 5 (out of 6) animals, respectively Animals treated with aqueous extract did not develop any toxicity sings such as muscle contractions, akinesia, dyspnea, and sedation. Thus, almost completely neutralized the lethal activity of 3LD50 (1.1 mg/kg b.w.) of the cobra venom and did not cause any types of adverse side effects to the animal models	Sivaraman et al., 2013
Leaves	Methanol	Antiemetic	Retching	Young male chicks at 4 days of age (32–52 g)	150 mg/kg b.w. p.o.	Decreased the mean number of retches	Hasan et al., 2012
Stem bark	Methanol	Hepatoprotective	Liver damage	Male albino Wistar rats (150–250 g and 12–14 weeks) with CCl_4-induced liver damage	200 and 400 mg/kgb.w. p.o. for 5 days (pretreatment)	Protected hepatic cells by decreasing alanine aminotransferase (ALT), serum glutamate pyruvate transaminase (SGPT), serum glutamate oxaloacetate transaminase (SGOT), and total proteins levels The higher dose significantly normalized defects in the histological architecture of the liver	Velmurugan and Ganesan, 2014

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TABLE 1 (Continued)

Plant part	Solvent used for extraction	Biological activity	Target pathology/disease	Experimental model	Extract administration	Effects	References
Leaves	Water	Anti-depressive and anti CNS disorders	Depression and CNS disorders	Swiss albino mice (6–8 weeks and 25–30 g)	200 mg/kg b.w. p.o.	Decreased immobility time duration in forced swim test (FST)	George et al., 2012
Leaves	Hydroethanol (n-butanol fraction)	Anti-dementia	Amnesia	Male Swiss albino mice (8 weeks and 25–30 g) with Scopolamine-induced amnesia	400 and 600 mg/kg b.w. p.o. orally per day for 21 days	Reduced scopolamine-induced increase in transfer latency (TL) and in time taken to reach reward chamber (TRC)	Yadav et al., 2018b
Stem bark	Methanol	Nootropic	Memory disorders	Male adult albino rats (220–250 g)	200, 400, and 600 mg/kg b.w. p.o. for 7 days	Improved both spatial reference and spatial working memories in the MWM test	Bithu et al., 2012
Stem bark	Methanol	Anticonvulsant	Convulsions	Swiss albino mice (18–25 g) with induced convulsions	200 and 400 mg/kg b.w. i.p.	Reduced maximal electroshock (MES) convulsions and pentylenetetrazole (PTZ)-induced convulsions	Velmurugan et al., 2012
Stem bark	Ethanol	Analgesic	Thermal heat pain	Male albino Wistar rats (150 ± 25 g)	300 mg/kg b.w. p.o.	Increased Eddy's hot plate reaction time	Manikandar et al., 2009
Stem bark	Petroleum ether	Antipyretic	Hyperpyrexia	Male albino Wistar rats (150 ± 25 g)	300 mg p.o/kg b.w. p.o.	Decreased Brewer's yeast-induced fewer	Manikandar et al., 2009
Roots	Ethanol	Analgesic	Thermal heat pain	Young Wistar rats (165–190 g)	200 mg/kg b.w. p.o.	Increased Eddy's hot plate reaction time Increased the time reaction in the tail immersion method	Kumar et al., 2011
Leaves	Water	Antipyretic	Hyperpyrexia and writhes	Swiss albino mice (6–8 weeks and 25–40 g) and male Wistar rats (150–200 g) with induced pyrexia	200 mg mg/kg b.w. p.o.	Decreased Brewer's yeast-induced fewer and reduced the number of writhes	Joseph et al., 2011
Leaves and fruits	Ethanol	Antipyretic	Hyperpyrexia	Albino rats (180–200 g)	200 and 300 mg/kg b.w. i.p.	Decreased Brewer's yeast-induced fewer	Ahmad et al., 2013
Stem bark	Methanol	Spasmolytic	Spasms	Jejunum remove from locally available rabbits (1–1.8 kg)	0.01–5.0 mg/ml	Caused relaxation of the spontaneous as well as K+ (80 mM)-stimulated contractions in isolated rabbit jejunum preparation with an EC_{50} values of 0.835 and 2.015 mg/ml, respectively	Janbaz et al., 2012
Stem bark	Methanol	Bronchodilator	Bronchoconstriction	Tracheas remove from locally available rabbits (1–1.8 kg)	0.01–5.0 mg/ml	Caused a complete relaxation of carbachol (1 μM)- and high K^+ (80 mM)-induced contractions in isolated rabbit tracheal preparation with EC_{50} values of 0.568 and 0.586 mg/ml, respectively	Janbaz et al., 2012

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TABLE 1 (Continued)

Plant part	Solvent used for extraction	Biological activity	Target pathology/disease	Experimental model	Extract administration	Effects	References
Stem bark	Methanol	Vasodilator	Vasoconstriction	Aortas remove from locally available rabbits (1–1.8 kg)	0.01–5.0 mg/ml	Caused a concentration-dependent relaxation of phenylephrine (1 μM)- and K^+ (80 mM)-induced contractions in isolated rabbit aorta rings with EC_{50} values of 0.513 and 0.525 mg/ml, respectively	Janbaz et al., 2012
Stem bark	Ethanol	Antihyperglycemic and antihyperlipidemic	Diabetes	Male Swiss albino mice (*Mus musculus*) (4–6 months and 20–30 g) with Alloxan-induced Diabetes	300 mg/kg b.w. p.o. for 45 days	Lowered blood glucose level by 27.3%, elevated hepatic glycogen content, and maintained body weight and lipid-profile parameters toward near normal range	Sharma et al., 2010
Stem bark	Ethanol	Hypolipidemic and antiatherosclerotic	hyperlipidemia	Male New Zealand white rabbits (1.25–1.50 kg and 10–12 months) with induced hyperlipidemia	500 mg/kg b.w. p.o. for 45 days	Reduced lipid profile parameters i.e., total cholesterol up to 88 %, LDL cholesterol-−95%, triglyceride 59%, and VLDL—cholesterol 60%, and reduced ischemic indices (total cholesterol/LDL-C and LDL-C/HDL-C) Significantly prevented atherogenic changes in the aorta	Purohit and Ram, 2012
Leaves	Hydroalcohol	Antihyperglycemic and antihyperlipidemic	Diabetes	Wistar albino rats (150–200 g) with Streptozotocin-induced diabetes	250, 500, and 750 mg/kg b.w.	Reduced the blood glucose level, serum levels of the total cholesterol, triglycerides, and increased HDL level	Sharma and Singla, 2013
Fruits	Ethanol	Hypolipidemic	Hyperlipidemia	Sprague Dawley rats (180–200 g) with Triton-induced hyperlipidemia	200, 400, and 600 mg/kg b.w.	Reduced serum cholesterol and serum LDL levels (200 mg/kg) Reduced serum levels of cholesterol, triglyceride, VLDL, LDL, and atherogenic index (400 and 600 mg/kg)	Jain and Surana, 2015
Stem bark	Chloroform	Antihyperglycemic and antihyperlipidemic	Diabetes	Male Wistar albino rats (190 ± 10 g) with Streptozotocin-induced diabetes	50 and 100 mg/kg b.w. p.o. for 21 days	Lowered the level of blood glucose, glycosylated hemoglobin, restored body weight, liver glycogen content, and serum insulin level, and decreased serum lipid profile markers and increased HDL level	Soni et al., 2018
Pods	Ethanol	Antihypercholesterolemic	Hypercholesterolemia	Adul male albino rabbits (1.5 ± 0.2 kg) with induced hypercholesterolemia *In vitro* HMG-CoA reductase assay	400 mg/kg p.o. for 45 days after induction of hypercholesterolemia 0.32–5 μg/ml	Reduced total cholesterol, LDL cholesterol, VLDL cholesterol, and triglycerides levels Reduced atherosclerotic plaque, intima, and media of the aortic wall as well as increased the lumen volume of the aorta The higher concentration showed a 67.1% inhibition of the activity of HMG-CoA reductase	Ram et al., 2022

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TABLE 1 (Continued)

Plant part	Solvent used for extraction	Biological activity	Target pathology/disease	Experimental model	Extract administration	Effects	References
Pods	Petroleum ether	Antihypercholesterolemic	Hypercholesterolemia	Adult male rabbits with induced hypercholesterolemia *In vitro* HMG-CoA reductase assay	400 mg/kg p.o. for 45 days after induction of hypercholesterolemia Not reported	Reduced the atherogenic index along with lipid profile The concentration of 5 μg/ml displayed a 53.1% inhibition of the activity of HMG-CoA reductase	Ram et al., 2022
Leaves	Ethanol	Wound healing	Excision wound	Albino Wistar rats (150–200 g)	200 mg/kg b.w. topically for 13 days	Exhibited a 92.13 ± 3.23 % reduction in wound area	Gupta et al., 2015
Leaves	Hydroethanol (butanol fraction)	Wound healing (anti-inflammatory, anti-collagenase, and anti elastase)	Excision and incision wound	Adult male Wistar albino rats (180–200 g)	5% and 10% ointment topically for 16 days	Repaired wound Increased hydroxyproline content Reduced epithelialization period and inflammatory markers in the blood Promoted collagen formation, re-epithelialization, angiogenesis, and the restoration of cutaneous appendages, i.e., hair follicles	Yadav et al., 2018a
Pods	Water and methanol	Antioxidant	Oxidative stress	*In vitro* lipid peroxidation inhibitory assay	250 μg/ml	Aqueous and methanol extract displayed lipid peroxidation inhibition by 79% and 65%, respectively	Liu et al., 2012
Stem bark	Methanol	Antioxidant	Oxidative stress	*In vitro* DPPH assay and superoxide asssay	1 mg/ml	Displayed DPPH radical scavenging activity of 31.80% and superoxide radical scavenging activity of 67.68%	Choudhary et al., 2011
Leaves	Methanol	Antioxidant	Oxidative stress	*In vitro* DPPH assay	Not reported	Displayed free radical scavenging activity (RSA) at a value of 60.48%	Abdul et al., 2012
Stem, leaves, and Bark	Ethanol	Antioxidant	Oxidative stress	*In vitro* DPPH assay	0.5 mg/ml	Displayed free radical scavenging activity (RSA) at a value of 82.19%, 71.16%, and 89.92%	Mohammad et al., 2013
Pods	Acetone, ethyl acetate, dichloromethane, methanol, and petroleum ether	Antioxidant	Oxidative stress	*In vitro* DPPH assay, ABTS assay, and FRAP assay	0.5–1 mg/ml	Acetone extract showed the highest DPPH scavenging activity followed by ethyl acetate and dichloromethane The antioxidant activity determined by ABTS assay was found to be highest in MeOH extract The maximum FRAP activity was found in dichloromethane extract followed by MeOH extract	Malik et al., 2013

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TABLE 1 (Continued)

Plant part	Solvent used for extraction	Biological activity	Target pathology/disease	Experimental model	Extract administration	Effects	References
Leaves	Hydroalcohol	Antioxidant	Oxidative stress	*In vitro* DPPH assay	10–80 μg/ml	Displayed antioxidant activity with IC_{50} value of 44.03 ± 1.96 μg/ml	Gupta et al., 2015
Leaves	Methanol and Water	Antioxidant	Oxidative stress	*In vitro* DPPH assay and reducing power assay	31.25–1,000 μg/ml	Methanol and aqueous extracts exhibited scavenging antioxidant activity with IC_{50} values range of 10.43–89.36 and 9.54–80.86 μg/ml, respectively Methanol and aqueous extracts displayed reducing activity of 0.063–0.828 and 0.543–0.730, respectively	Mohan et al., 2017
Leaves	Hydroethanol (n-butanol, chloroform, and ethyl acetate fractions)	Antioxidant	Oxidative stress	*In vitro* DPPH assay *In vitro* AChE inhibition assay	Not reported	Exhibited scavenging DPPH antioxidant activity with IC_{50} values of 19.85 ± 1.34, 42.80 ± 2.23, and 107.82 ± 1.71 μg/ml Displayed inhibitory activity with IC50 values of 11.06 ± 3.61, 22.35 ± 2.73, and 66.88 ± 3.45 μg/ml	Yadav et al., 2018a
Leaves	Hydroethanol (n-butanol, chloroform, and ethyl acetate fractions)	Antioxidant	Oxidative stress	*In vitro* ABTS assay	Not reported	Extract fractions displayed antioxidant activity with IC_{50} values of 22.4668 ± 1.42, 59.0519 ± 1.65, and 93.0167 ± 1.04 μg/ml	Yadav et al., 2018a
Fruits	Ethanol and water	Antioxidant	Oxidative stress	*In vitro* Phosphomolybdenum assay, DPPH assay, FRAP assay, and ferrozine assay	0.5–20 mg/cm^3	Ethanolic extract displayed total antioxidant capacity in mg ascorbic acid equivalents of 0.025 ± 0.011 (2.5 mg/cm^3) and 0.026 ± 0.012 (3.0 mg/cm^3), while aqueous extract displayed 0.021 ± 0.066 (2.5 mg/cm^3) and 0.027 ± 0.077 (3.0 mg/cm^3) Ethanolic and aqueous extracts exhibited scavenging antioxidant activity with IC_{50} (mg/cm^3) values of 7.026 ± 0.088 and 4.097 ± 0.033, respectively Ethanolic and aqueous extracts displayed FRAP value (mg Fe (II) eqv/g) of 2.742 ± 0.023 and 17.951 ± 0.026, respectively Ethanolic and aqueous extracts exhibited reducing power of antioxidants measured in terms of ascorbic acid equivalents (mg AE/g) of 4.767 ± 0.4877 and 10.370 ± 0.005, respectively	Ansari et al., 2021
Pods/Seeds	Methanol	Antioxidant	Oxidative stress	*In vitro* DPPH assay	25, 50, 100, and 200 μg/ml	Displayed activity with IC_{50} value of 30.0 μg/ml	Asati et al., 2021

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TABLE 1 (Continued)

Plant part	Solvent used for extraction	Biological activity	Target pathology/disease	Experimental model	Extract administration	Effects	References
Leaves	Ethanol	Antioxidant	Oxidative stress	*In vitro* DPPH assay	0.00781–1 mg/ml	Exhibited minimum DPPH scavenging activity (59%) at 0.0156 mg/ml and maximum activity (98.33%) at a 1 mg/ml	Akhtar et al., 2022
Pods	Water and methanol	Anti-inflammatory	Inflammation	*In vitro* COX-1 and−2 enzymes inhibitory assay	250 μg/ml	Aqueous extract inhibited COX-1 and−2 enzymes by 51 and 45% Methanol extract inhibited COX-1 and−2 by 57 and 34%	Liu et al., 2012
Stem bark	Hydroethanol	Anti-inflammatory	LPS-induced inflammation	Swiss albino male mice (20–30 g)	100, 300 mg/kg b.w. for 7 days and after 14 days of LPS intoxication	Suppressed the over-expression of cytokines and restored the levels of TNF-α, NF-κB, NO, IL-6, IFN-γ, prostaglandin E2, and IL-10	Sharma and Sharma, 2020
Stem bark	Chloroform, methanol, and water	Antibacterial	Bacterial infection	*In vitro* agar well diffusion assay	250 μg/ml	Exhibited activity against *Salmonella typhi* [zone of inhibition (ZOI): 9, 13, and 10 mm], *Bacillus lintus* (ZOI: 16, and 11 mm), *Klebsiella pneumonia* (ZOI: 6, 12, and 13 mm), *Streptomyces griseus* (ZOI: 6, 11, and 11 mm), *Bacillus subtilis* (ZOI: 7, 12, and 12 mm), *Staphylococcus aureus* (ZOI: 10, 13, and 13 mm), *Staphylococcus albus* (ZOI: 9, 14, and 12 mm), *Escherichia coli* (ZOI: 11, 14, and 6 mm), and *Pseudomonas aeruginosa* (ZOI: 6, 15, and 16 mm)	Velmurugan et al., 2010
Pods	Acetone	Antibacterial	Bacterial infection	*In vitro* agar well diffusion assay	Not reported	Exhibited activity against *Staphylococcus aureus* (ZOI 19 ± 0.21 mm), *Staphylococcus epidermidis* (ZOI: 15 ± 1.04 mm), and *Escherichia coli* (ZOI: 17.2 ± 0.40 mm)	Raj and Anjali, 2010
Leaves	Methanol	Antibacterial	Bacterial infection	*In vitro* agar well diffusion assay	1–15 mg/ml	The higher concentration displayed activity against *Bacillus subtilis* (ZOI of 18 mm), *Escherichia coli* (ZOI of 15 mm), *Vibrio cholera* (ZOI of 19 mm), and *Enterobacter aerogenes* (ZOI of 15 mm)	Abdul et al., 2012

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TABLE 1 (Continued)

Plant part	Solvent used for extraction	Biological activity	Target pathology/disease	Experimental model	Extract administration	Effects	References
Stem, leaf, and bark	Ethanol	Antibacterial	Bacterial infection	*In vitro* agar well diffusion assay	0.5 mg/ml	Stem extract displayed antibacterial activity against *S. typhi* (71.95 ± 0.25 mm ZOI), *E. coli* (75.17 ± 0.61 mm ZOI), *P. aeroginosa* (56.74 ± 1.63 mm ZOI), *B. subtilis* (55.00 ± 0.44 mm ZOI), and *S. aerus* (51.73 ± 1.20 mm ZOI) Leaf extract displayed antibacterial activity against *S. typhi* (72.40 ± 1.90 mm ZOI), *E. coli* (73.28 ± 0.94 mm ZOI), *P. aeroginosa* (65.23±0.23), *B. subtilis* (57.56 ± 1.67 mm ZOI), and *S. aureus* (56.60±3.27 mm ZOI) Bark extract displayed activity against *S. typhi* (69.05 ± 2.15 mm ZOI), *E. coli* (66.22 ± 4.57 mm ZOI), *P. aeroginosa* (61.51 ± 1.63 mm ZOI), *B. subtilis* (52.50 ± 1.06 mm ZOI), and *S. aerus* (51.27 ± 4.73 mm ZOI)	Mohammad et al., 2013
Leaves	Ethyl ether and alcohol	Antibacterial	Bacterial infection	*In vitro* agar well diffusion assay	Not reported	Ether extract inhibited the growth of *S. aureus* (0.80 I/Ca and 0.93 I/Pa), *E. coli* (0.97 I/Ca and 0.88 I/Sa), and *C. albicans* (0.62 I/ma) Alcoholic extract inhibited the growth of *S. aureus* (0.74 I/Ca and 0.86 I/Pa), *E. coli* (0.89 I/Ca and 0.83 I/Sa), and *C. albicans* (0.86 I/ma)	Kapoor and Bansal, 2013
Aerial portions	Methanol (ethyl acetate fraction)	Antibacterial	Bacterial infection	*In vitro* antimicrobial susceptibility test performed using the broth micro-dilution method	Serial dilution from 64 to 0.006 mg/ml	Displayed activity against *E. coli* (MIC: 1 mg/ml), *S. aureus* (MIC: 0.25 mg/ml), *K. pneumoniae* (MIC: 1 mg/ml), *E. faecium* (MIC: 0.25 mg/ml), *E. faecalis* (MIC: 0.031 mg/ml), and *A. baumannii* (MIC: 0.25 mg/ml)	Neghabi-Hajiagha et al., 2016
Leaves	Methanol	Antibacterial	Bacterial infection	*In vitro* disc diffusion method	200 mg/ml	Exhibited activity *against Staphylococcus aureus*, *Streptococcus pneumoniae*, *Bacillus cereus*, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Salmonella typhi* with a zone of inhibition (ZOI) ranging from 8 to 11 mm	Mohan et al., 2017

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TABLE 1 (Continued)

Plant part	Solvent used for extraction	Biological activity	Target pathology/disease	Experimental model	Extract administration	Effects	References
Leaves	Water, ethanol, and methanol	Antibacterial	Bacterial infection	*In vitro* agar well diffusion method	50 mg/ml	Different proteins displayed activity against *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Aspergillus tubingensis* with a zone of inhibition (ZOI) range between 1.5 ± 0.01 and 8.1 ± 0.07 mm	Kulshreshtha et al., 2019
Leaves	Methanol	Antifungal	Fungal infection	*In vitro* agar tube dilution method	15 mg/ml	Exhibited an inhibition activity of 15.38% for *Aspergillus niger* and 8.00% for *Aspergillus fumigatus*	Abdul et al., 2012
Stem bark	Methanol and chloroform	Anthelmintic	*Phretima posthuman* infection	Anthelmintic assay	20–160 mg/ml	Methanol caused paralysis (in 25.23–32.11 min) and death (in 62.09–69.12 min) of *Phretima posthuman* Chloroform extract caused paralysis (in 35.59–42.16 min) and death (in 70.07–80.20 min) of *Phretima posthuman* Aqueous extract caused paralysis (in 29.34–36.26 min) and death (in 66.05–75.42 min) of *Phretima posthuman*	Velmurugan et al., 2011
Leaves, stem, flowers, and roots	Ethyl acetate	Antimalarial	*P. falciparum* infection	*In vitro* antimalarial screening	12.5–200 μg/ml for 48 h	Ethyl acetate extract displayed activity against CQ-sensitive *P. falciparum* 3D7 strain with IC_{50} values of 30.67 (leaves), 36.00 (stem), 27.33 (flowers), and 41.00 μg/ml (roots) Chloroform extract displayed activity against CQ-sensitive *P. falciparum* 3D7 strain with IC_{50} value of 59.00 (leaves), 67.67 (stem), 76.67 (flowers), and 40.33 μg/ml (roots) Aqueous extract displayed activity against CQ-sensitive *P. falciparum* 3D7 strain with IC_{50} value of 61.67 (stem), 55.37 (flowers), and 71.00 μg/ml (roots)	Satish et al., 2015
Leaves	Methanol	Cancer chemoprevention	Liver tumor	Male Wistar albino rats (6–8 weeks) with DEN-induced experimental liver tumor	200 and 400 mg/kg b.w. orally by gavage for 20 weeks from the first dose of DEN	Increased the levels of membrane-bound enzymes like Na+/K+ ATPase, Mg^{2+} ATPase, and Ca^{2+} ATPase Reduced the levels of glycoproteins like hexose, hexosamine, and sialic acid	Maideen et al., 2012

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TABLE 1 (Continued)

Plant part	Solvent used for extraction	Biological activity	Target pathology/disease	Experimental model	Extract administration	Effects	References
Leaves	Methanol	Cancer chemoprevention	Liver tumor	Male Wistar albino rats (6–8 weeks) with DEN-induced experimental liver tumor	200 and 400 mg/kg b.w. orally by gavage for 20 weeks from the first dose of DEN	Increased N-nitrosodiethylamine (DEN)-induced elevated levels of alfa feto protein (AFP) and lipid peroxidation (LPO) Enhanced antioxidant defense system by increasing enzymatic antioxidants (superoxide dismutase, catalase, and glutathione peroxidase) and non-enzymatic antioxidants (reduced glutathione, vitamin C, and vitamin E) levels	Maideen et al., 2012
Pods/Seeds	Methanol	Cytotoxicity	Hepatocellular carcinoma (Huh7 cell line)	*In vitro* MTT assay	50–200 μg/ml for 48 h	Exhibited a cell viability decrease with an IC_{50} value of 150 μg/ml	Asati et al., 2021

cream. Besides, the evaluation of the test on depilation resistance on the back of mice resulted in a weight ratio of depilated hair of 200% compared to the control group suggesting that the depilatory cream reduced the amount and impairs the robustness of undesired hair reducing the need for depilation sessions. The authors concluded that the herbal depilatory cream was successfully developed using leaves of *P. cineraria*.

Prosopis cineraria components reclaim beneficial biological activities

As previously stated, *P. cineraria* can be exploited for numerous applications and none of the portions that make up the plant is discarded, but each one gives important pharmacological and cosmetic properties to the extracts for these uses. The presence of phytomolecules is promising in the synthesis of cosmetic formulations (Verma et al., 2011; Mohammad et al., 2015, 2018; Sharifi-Rad et al., 2019). As mentioned above, most articles explain the effectiveness of the phytochemicals in Ghaf as antioxidants or for other pharmaceutical applications (Abdul et al., 2012; Mohammad et al., 2013; Jain and Surana, 2015; Afifi and Al-rub, 2018; Kulshreshtha et al., 2019; Sharifi-Rad et al., 2019; Ansari et al., 2021; Bhardwaj and Al Khaimah, 2021; Akhtar et al., 2022; Zhong et al., 2022). In contrast, in cosmetics, the literature is still poor, and formulations may contain substances, such as PEG or liquid paraffin, which are not appreciated (Verma et al., 2011; Mohammad et al., 2015, 2018). In fact, from a careful global perspective on sustainability, new raw materials should be exploited to satisfy the customers in the choice of specific products referring to INCI (International Nomenclature of Cosmetic Ingredients), which allows them to know the ingredients of cosmetic formulations. Most of the molecules, in *Prosopis*, are classified as good or biocompatible according to the INCI, as reported in detail in Table 2.

In principle, all the main components are appealing to avail substances obtainable from *P. cineraria*:

- Seeds: 25–35 per pod, have a rhomboid or oblong shape, and are brown. Many molecules can be extracted from these seeds (Gangal et al., 2009; Garg and Mittal, 2013; Pareek et al., 2015; Afifi and Al-rub, 2018; Imam et al., 2019), including oils and actives. Indeed, both saturated and unsaturated fatty acids such as oleic and linoleic acids have been found in *P. cineraria*. Some of these extracts can be applied for creating a face, hand, anti-aging, and hair masks and lipsticks. Fatty acids are employed as emollients capable of softening and smoothing the skin and as emulsifying agents. Gallic acid and rutin are antioxidants that prevent rancidity and oxidation and can be used in anti-aging face creams with properties comparable to luteolin.

TABLE 2 Formulation effect of the principal compounds in *P. cineraria* according to INCI.

Compound name	Plant part	Chemical group	Formulation effect
Alanine, arginine, aspartic acid, cysteine, glutamic acid, glycine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine proline, serine, threonine, tyrosine, valine	Leaf, pod	Aminoacid	Used as antistatic, antioxidant, humectant, pH regulator, odor masking, and skin/hair conditioning
β- Sitosterol, campesterol, cholesterol, stigmasterol	Flower, leaf, seed	Sterol	Used as emollient, emulsifying, odor masking, skin conditioning, stabilizing, and viscosity controlling
Fructose, glucose, rhamnose, sucrose	Pod, bark	Sugar	Used as humectant for body cream and lotion, odor masking, skin conditioning, and soothing for skin (and lip) care
Gallic acid	Seed	Phenol	Used as antioxidant
Lignin	Bark	Polyphenol	Used as UV protection, antioxidant, anti-aging, and antimicrobial activity
Linoleic acid, methyl docosanoate or methyl behenate, N-octacosyl acetate or stearyl acetate, oleic acid	Bark, leaf, pod, seed	Fatty acid and derivatives	Used as antistatic, cleansing, emollient, emulsifying, humectant, hair, and skin conditioning
Luteolin, rutin	Flower, Seed	Flavonoid	Used as antioxidant, hair, and skin conditioning
Maslinic acid-3-glucoside	Pod	Triterpenoid	Used as antioxidant and skin conditioning.
Saponin			Used as cleansing, emulsifying, and surfactant
Starch	Bark	Polysaccharide	Used as absorbent, anticaking, humectant, skin protecting, and viscosity control

- Pods: yellow to reddish brown with cylindrical shape and 20-cm long by 0.8-cm thick. The main extracted molecules are fructose, alkaloids such as prosophylline, amino acids, saponin, 3-benzyl-2-hydroxy-urs-12-en-28-oic acid, and maslinic acid-3-glucoside (triterpenoids); flavonoids such as vitexin, puerarin, phloridzin, and daidzein; linoleic acid; 5,5′-oxybis-1,3-benzenediol and 5,3′,4′-trihydroxyflavanone 7-glycoside (polyphenols) (Karim and Azlan, 2012; Liu et al., 2012; Garg and Mittal, 2013; Afifi and Al-rub, 2018; Asati et al., 2022; Ram et al., 2022; Zhong et al., 2022). In particular, the amino acids isolated from both leaves and pods are Asp, Glu, Ser, Gly, His, Thr, Arg, Ala, Pro, Tyr, Val, Met, Cys, Ile, Leu, Phe, and Lys (Khatri et al., 2010). These molecules are also well-received by INCI. The listed amino acids are used in the formulation of skin and hair care. The addition to the formulations of flavonoids, such as those mentioned above, provides benefits against skin aging.
- Leaves (Malik and Kalidhar, 2007; Garg and Mittal, 2013; Mohammad et al., 2013; Pareek et al., 2015; Afifi and Al-rub, 2018; Islam et al., 2019; Kulshreshtha et al., 2019; Sharifi-Rad et al., 2019): gray green with an oblique shape. Besides the same amino acids detected in the pods (Khatri et al., 2010), phytoconstituents can be extracted from the leaves, including campesterol, cholesterol, sitosterol, stigmasterol, octacosanol, hentriacontane, methyl docosanoate, diisopropyl-10,11-dihydroxyicosane-1,20-dioate, tricosan-1-ol, and 7,24-tirucalladien-3-one, and quercetin derivatives (Akhtar et al., 2022). Leaves are already employed to treat mouth ulcers or to treat open sores on the skin (Afifi and Al-rub, 2018). The extracted compounds are good according to INCI and can be applied to body and face creams, emulsions, and lotions. Moreover, the presence of phytosterols and, fatty alcohols, such as tricosan-1-ol allows for better skin hydration, reducing the erythema index, and protecting the skin from stress phenomena. It could be able to improve the stability and smoothness of formulations, donating them consistency given the long carbon chain playing a role in the chemical–physical properties.
- Flowers (Khatri et al., 2010; Garg and Mittal, 2013; Pareek et al., 2015; Afifi and Al-rub, 2018): yellow, thin, and pedunculated around 10 cm long. From flowers, it is possible to isolate molecules such as patuletin, patulitrin, luteolin, rutin, sitosterol, spicigerine, prosogerin A and B. Some of these have been already described previously and used in cosmetics (refer to Table 2). Furthermore, flowers are a fundamental resource for bees in obtaining honey. This product can be used as an emollient, humectant, and soothing and prevents pathogenic infections.
- Bark (Garg and Mittal, 2013; Pareek et al., 2015; Afifi and Al-rub, 2018; Mohammad et al., 2018) and trunk can be exploited in extracting lignin and starch, already used in cosmetics. Other molecules obtainable from the purification of these components are hexacosan-25-on-1-ol, vitamin K1, n-octacosyl acetate, glucose, rhamnose, and

sucrose (Islam et al., 2019). As previously mentioned, the advantage of fatty alcohols, in this case, hexacosan-25-on-1-ol, can change the consistency of the formulation. While molecules such as glucose, rhamnose, and sucrose are often used as humectants and soothing agents in formulations such as creams, scrubs, and shower gels.

Eventually, a resin tree or Mesquite Gum can be obtained from the plant and employed for encapsulation of active compounds, fragrances, and natural colors, acting as an emulsifier in oil-to-water processes (Afifi and Al-rub, 2018; Mudgil and Barak, 2020; Vadapalani Nallasivam and Gokhale, 2022).

Discussion

The Ghaf (i.e., *P. cineraria*), the national tree of the UAE, is known for its ability to withstand and thrive in challenging environmental conditions. It serves as a hopeful symbol for the important work being carried out to advance farming methods across the Emirates. For countries like UAE, where arid conditions are present, identification of such tree that is considered resident, resistant, and remedial becomes an opportunity for agroforestry. Investigative research targeting the commercialization of Ghaf tree products, including extracting, manufacturing, and marketing operations would be useful in achieving a triple bottom line of sustainability. Such research would support not only ecological biodiversity but also economic viability through Ghaf tree production in the UAE. Due to remedial benefits and local traditions, there is a great potential for commercialization of the Ghaf tree as the research found that despite the Western medicine adoption of the country in its healthcare system, herbal medicines, and remedies are also commonly used by the UAE nationals (AlBraik et al., 2008).

From a nutritional point of view, *P. cineraria* seeds are very important as they are considered a potential and cheap source of protein for industrial use, especially for numerous people in Africa and Asia who are suffering from protein and mineral deficiency due to malnutrition problems. By a grinding process of the mesocarp part of its pods, is obtained flour that contains 62% of proteins, 25% of dietary fiber, a large amount of free polyphenols and carotenoids, and low content of total carbohydrates and fat, as well as a source of calcium, potassium, magnesium, zinc, and iron (Afifi and Al-rub, 2018). Its pods are known to be rich sources of vitamin C, calcium, and iron, and to be effective in the prevention of protein–calorie malnutrition and iron–calcium deficiency in the blood (Asati et al., 2022). It is much higher in lysine than the other cereals and it is particularly appropriate for vegetarians who often lack this amino acid. Moreover, the flour is particularly suitable for patients with diabetes because the pods contain fructose which the body can metabolize without insulin and helps keep blood sugar constant over time. In fact, studies showed that it releases sugars into the blood much more slowly than wheat flour (Pasiecznik et al., 2007).

As the Ghaf can grow without irrigation and fertilization, it may create an economical advantage due to its low maintenance costs, and if the tree can be fully utilized, it could take its place in the UAE economy as an attractive agricultural investment tool. At the same time, the economic contribution of the tree may provide various benefits to the social sustainability of the country in terms of job creation and increasing quality of life, health, and well-being. For all these reasons, it is very important to create a market for the products to be obtained from the Ghaf tree. Provided that the nutritional values of this plant, as well as the potential curative effects of the extracts from its various components have been established, novel sustainable opportunities for the development of innovative products also in side fields with high economic impact, including cosmetic and luxury, are readily expected. To determine the actual potential of these products, first of all, intense scientific research is needed to challenge new isolation, production, and scale-up processes. Among the different challenges in which researchers and companies are trying to act promptly, *P. cineraria* is estimated to have a big impact on the eco-sustainability of products by reducing waste of resources and employing eco-friendly materials (natural origin or renewable biomass). In particular, the research effort should apply to all the components of cosmetics and luxury in general, spanning from formulation to packaging. The concept of eco-sustainability is closely related to green chemistry and more rational use of resources such as water and renewable and clean energy sources. Especially with the rise in Earth's temperature, the disproportionate use of resources in all productivity fields, including pharma, food, and luxury, must be stopped.

Conclusion

Sustainability is increasingly considered the new frontier of luxury. Starting from this assumption, the above considerations suggest that the cosmetic products obtained by *P. cineraria* could be able to perfectly combine these two concepts paving the way to a new era of eco-luxury.

Indeed, a critical issue relating to the widespread increase of luxury and cosmetics in the marketplace, which must be considered urgently, concerns microplastic replacement. This concrete problem is leading to consequences for the entire ecosystem damaging the flora and fauna of the planet. In fact, from recent studies, microparticles were detected in the respiratory and circulatory human systems (Jenner et al., 2022;

Leslie et al., 2022). The use of raw materials from natural sources, such as *P. cineraria*, turns out to be a valid alternative to hit the targets. As mentioned, it is a plant able to grow in hostile environments by also providing nutrients for populations of Western Asia and the Indian Subcontinent. This plant can be a weighty competitor compared to eco-friendly components already used in different formulations, not only reaching the mentioned goals but also fighting the greenwashing concept by exploiting the 3G principle: "Give a Ghaf as a Gift" from nature.

Author contributions

MC and PG conceived the study. MG, FC, YA, and MC wrote the first draft. TAA, LS, PG, and DP reviewed and edited the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

Author TAA was employed by company Goumbook.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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