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Pharmacological potential of *Portulacaria afra:* A review on bioactive compounds, pharmacological uses and therapeutic prospects

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ABSTRACT

There has been a notable increase in the use of ethnomedicines in developing nations, primarily due to their low cost, widespread availability, and the belief that they are safer alternatives to conventional medicines. *Portulacaria afra (P. afra)*, a medicinal plant native to South Africa, has been traditionally used in treating diseases such as diabetes, diarrhoea, fever, hypertension, and various skin and blood disorders. This review examines the pharmaceutical potential of *P. afra*, focusing on its bioactive compounds, pharmacological uses, and therapeutic potential. Various approaches were used to gather relevant data, including searches through databases such as Google Scholar, PubMed, and ScienceDirect. *In vitro* studies have demonstrated multiple biological activities, including antioxidant, anti-inflammatory, anti-diabetic, anti-bacterial, and cytotoxic effects. Phytochemical analysis has identified groups of compounds in *P. afra*, such as flavonoids, phenolic acids, alkaloids, saponins, tannins, and glycosides. Bioactive compounds such as lupeol and piperidine have also been identified recently. However, a major limitation is that these pharmacological findings are confined to *in vitro* studies, with little or no significant *in vivo* studies to validate these effects. Hence, further research is essential to assess the pharmacological activities *in vivo*, clinical efficacy, safety of *P. afra*, and the therapeutic mechanism(s) to understand its folkloric use as a possible candidate in modern therapeutics.

Introduction

Plants have been a vital source of medicines, both therapeutic and prophylactic and health-promoting agents, for centuries. About 80% of the African population still depends on traditional medicine for primary healthcare needs [1]. The reliance of Africa on traditional therapies can be attributed to the high cost and availability of conventional medicines, especially in rural areas. The growing use of medicinal plants in managing diseases has sparked curiosity in identifying and characterising the active chemicals responsible, as well as the questions on their safety uses.

P. afra, commonly known as the 'Speekboom' or 'Elephant bush', is a succulent herb belonging to the Portulacaceae family. The family *Portulacaceae* consists of a single genus called Portulaca, which comprises 115 species distributed worldwide. *P. afra* is

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indigenous to South Africa and thrives on sloping terrains with good drainage, particularly in the Western Cape Limpopo provinces [2]. The plant is characterised by its perennial, succulent leaves, reddish-purple stems, and pink flowers that bloom in the spring/summer flowering period [3]. Fig. 1 shows the image of a *P. afra* plant.

The folkloric use of *P. afra* in treating various diseases has been documented. The leaves have been used as a galactagogue in nursing mothers [4]. Due to their high-water content, the tangy-flavoured leaves are often sucked to relieve dehydration. Applying crushed leaves on blisters and corns on the feet alleviates discomfort. Additionally, the plant is a common treatment for oral infections and skin conditions such as sunburn pimples, rashes, sores, eczema, and insect stings [5]

While *P. afra* is not typically considered a primary food source for humans, it has been acknowledged for its nutritional value and potential culinary use. In South Africa, *P. afra* leaves can be added to salads as a cost-effective alternative to green leafy vegetables [6]. The leaves are used locally to produce high-quality preserved items such as pickles, chutney, and spices [6]. The *P. afra* is also recognised as an ornamental plant that enhances agroforestry systems [7]. Recent research has demonstrated that the plant is highly effective at sequestering atmospheric carbon [8].

While there is plenty of literature on the phytochemical composition and therapeutic potential of other plants in the genus *Portulaca*, such as *Portulaca oleracea* (purslane), significant research on *P. afra* is still lacking. The current study is based on a review of existing literature on the biological activities, phytochemical composition, and potential areas for future pharmaceutical application of *P. afra*-derived extracts. This review covers the utilisation of the plant in traditional medicine, its phytochemical composition, and the scientifically validated biological activities associated with its active compounds. This review article establishes a basis for future research endeavours and the formulation of therapeutic agents derived from this plant.

Methods and materials

All relevant data about the ethnomedicinal applications, phytochemical composition, and pharmacological properties of *P. afra* were collected from published literature. Electronic databases such as Google Scholar, PubMed, Science Direct, and Scopus were also used to collect relevant information. The keywords used for the search include "*Portulacaria afra*", "phytochemistry", "antioxidant"; "anti-inflammatory", "and ethnopharmacology". A total of 300 articles were yielded with no timeline. After applying specific inclusion and exclusion criteria, only 11 articles were selected as summarised in Table 1. This review was presented in the current format to allow a broader exploration of the topic.

The following inclusion criteria were used for the selection:

1. Research articles on the phytochemical determination of *P.afra* extracts.
2. Studies on the traditional medicinal uses of *Portulacaria afra.*
3. Research articles on biological activities of *P. afra* extracts using *in vitro* or *in vivo* methods
4. The exclusion criteria were set to exclude the following articles.
5. Articles that report on *Portulacaria afra* as forage.
6. Articles that report on the environmental uses of *Portulacaria afra.*

Phytochemistry of *Portulacaria afra*

P. afra possesses an array of phytochemicals that show physiological effects, thus accounting for its therapeutic potential in various illnesses. The phytochemical analysis of the leaves, stem and root extracts revealed the presence of major classes of phytochemicals.

Fig. 1. Image showing *P. afra* plant. Adapted from Adeleye and Risenga [9].

Table 1
Summary of literature search.

S/N	Articles	Reference
1	Phytochemical profiling, antioxidant, anti-inflammatory, Thrombolytic, hemolytic activity *in vitro* and in silico Potential of *portulacaria afra*	[10]
2	A short communication on the ethnobotany, phytochemistry, pharmacological evidence and ecosystem restoration potential of South African *Portulacaria afra*	[7]
3	A phytochemical screening, antioxidant and anti-bacterial activity analysis in the leaves, stems and roots of *Portulacaria afra*	[11]
4	Phytochemical, biological, and *in-silico* characterization of *Portulacaria afra* Jacq.: A possible source of natural products for functional food and medicine	[12]
5	The *in vitro* assessment of anti-diabetic activity of the plant extracts obtained from *Portulacaria afra* jack. Grown under concurrent extreme temperatures and water-deficit conditions	[13]
6	Screening of phytochemical profile and biological activities in the leaves, stems and roots of south african *Portulacaria afra* using four extraction solvents	[9]
7	Effect of concurrent extreme temperatures and water deficit on the phytochemistry, anti-microbial and antioxidant activities of *Portulacaria afra* using four extraction solvents	[13]
8	Phytochemical profiling, anti-inflammatory, analgesic and antipyretic potentials of *Portulacaria afra* Jacq: Molecular docking of unexplored bioactive compounds	[10]
9	Investigation of bioactive constituents and evaluation of different *in vitro* anti-microbial, antioxidant, and cytotoxicity potentials of different *Portulacaria afra* extracts	[14]
10	The effect of elevated carbon dioxide on the medicinal properties of *Portulacaria afra*	[15]
11	Green synthesis of silver nanoparticles using *Portulacaria afra* plant extract: characterization and evaluation of its anti-bacterial, anti-cancer activities	[16]
12	Chemical profiling and evaluation of toxicological, antioxidant, anti-inflammatory, anti-nociceptive and tyrosinase inhibitory potential of *Portulacaria afra* using *in-vitro, in-vivo* and *in-silico* studies	[17]
12	The physicochemical and nutritional value of fresh and processed *Portulacaria afra* (spekboom) leaves	[18]
13	Phytochemical screening, antioxidant, anti-inflammatory, and glucose utilization activities of three south african plants used traditionally to treat diseases	[4]

Table 2 shows the major phytochemical compounds reported from different parts of the *P. afra* plant.

Flavonoids

Flavonoids are reputed phenolic compounds containing hydroxyl groups and are synthesised by plants to react to microbial infection. These plant metabolites are well-known for their health-enhancing properties in humans, which include anti-inflammatory,

Table 2
Phytochemical compounds in *Portulacaria afra*.

Plant part	Phytochemicals	Solvent of extraction	Biological activities	Reference
Leaves	Saponins, glycosides, phenolics, tannins, terpenoids, steroids, coumarins, phlobatannins, volatile oils	Methanolic	Antioxidant, anti-bacterial	[11]
	Quinones, phenols, steroids and coumarins	Methanolic	Antioxidant, anti-bacterial	[9]
	Saponins, terpenoids, quinones and coumarins	Water	Antioxidant, anti-bacterial	[9]
	Tannins, moderate presence of phytosteroids and a low presence of volatile oil	Ethyl acetate	Antioxidant, anti-bacterial	[9]
	Tannin, flavonoids, alkaloids, phytosterol, saponins, cardiac glycoside quinolones, and triterpenoids	Methanol	Antioxidant, anti-inflammatory, anticholinesterase	[10]
Stem	Terpenoids, steroids, phenols and coumarins.	Methanolic	Antioxidant, anti-bacterial	[9]
Roots	Of volatile oil tannins and steroids	Ethyl acetate	Antioxidant, anti-bacterial	[9]
	Phenolic compounds, flavonoids	Aqueous	Antioxidant, anti-bacterial	[9]
Leaves	Alkaloids, tannins, phenols, flavonoids, saponins, glycosides. Resins	N-hexane	Antioxidant, thrombolytic, hemolytic activity, anti-acetylcholinesterase, anti-butyrylcholinesterase, anti-inflammatory	[10]
	Alkaloids, tannins, phenols, flavonoids, saponins, glycosides. Resins	Chloroform	Antioxidant, thrombolytic, hemolytic activity, anti-acetylcholinesterase, anti-butyrylcholinesterase, anti-inflammatory	[10,17]
	Phenols, flavonoids, saponins, resins	N-butanol	Antioxidant, thrombolytic, hemolytic activity, anti-acetylcholinesterase, anti-butyrylcholinesterase, anti-inflammatory	[10]
	Alkaloids, tannins, phenols, flavonoids, saponins, glycosides. Resins	Methanol	Antioxidant, thrombolytic, haemolytic activity, anti-acetylcholinesterase, anti-butyrylcholinesterase, anti-inflammatory	[10,17]
Leaves	Flavonoids, phenols	Acetone	Glucose utilisation activities, antioxidant, anti-inflammatory	[4]

anti-microbial, anti-oxidative, anti-cancer, antimutagenic, antiallergic, and vascular activities among others [19,20]. Several qualitative studies have shown the presence of flavonoids in the leaves, stems, and root extracts of *P. afra* [21]. To date, no study has isolated specific flavonoids from the plant. However, total flavonoid content has been determined using different extraction solvents. The methanolic stem extract of *P. afra* has shown the overall highest total flavonoid content of 901.30±149.87 mg/g compared to the root and leaf extract [9]. In another study, the *n*-hexane extract of the whole plant contained the highest value of total flavonoid content, of 831.58 mg quercetin equivalent/g compared to the hydro-methanol and chloroform extract [10].

Phenolic acids

Phenolic acids are benzoic and cinnamic acid derivatives widely distributed in cereal grains, fruits, and vegetables [22]. They are known for their antioxidant and anti-inflammatory activity, thus justify their folkloric use in cardiovascular diseases and cancers [23]. They also exhibit hypoglycemic activity [24]. The major phenolic acids that have been identified in *P. afra* extract include 3-Methyl-4--propan-2-ylphenol, 3-Alkyl-6-methoxyphenol, Acetic acid;2,4-ditert-butylphenol, 2,6-Dimethoxy-4-[(E)-prop-1-enyl] phenol and Phenol, 2, 4-bis (1, 1-dimethyl ethyl) [10,12]. However, these identified compounds have not been linked to any pharmacological activity.

Terpenoids and triterpenoids

Terpenoids are a class of volatile compounds that typically influence the taste and smell of plants and flowers. They are commonly present in the leaves and fruit of angiosperms, gymnosperms, citrus trees, and eucalyptus trees. Several qualitative phytochemical screening studies have shown the presence of terpenoids *in P. afra* extracts [10,14,18]. For the first time, lupeol, a triterpenoid, was isolated from extracts of *P. afra* [14]. Lupeol has been shown to exhibit various pharmacological activities under *in vitro* and *in vivo* conditions. These include its beneficial activity against inflammation, cancer, arthritis, diabetes, heart diseases, renal toxicity and hepatic toxicity [25]. Others terpenoids identified include 2E,4E) −5-(1,3-Benzodioxol-5-yl)−1-piperidin-1-ylpenta-2,4 dien-1-one and phytol [10,17].

Glycosides

Plant glycosides are secondary metabolites in which a sugar moiety (glycone) is bound to a non-sugar functional group (aglycone) via a glycosidic bond, and many plants preserve chemicals as inactive forms of glycosides [26]. Isolation or mass spectrophotometric fingerprinting has not been conducted to determine glycosides in *P. afra* extracts. Nevertheless, some studies have revealed the presence of glycosides such as coumarins, quinones, cardiac glycosides, and saponins in leaf, stem, and root extracts of *P. afra* [9,10, 17]. In a study by Bassom and colleagues, [11] a strong presence of coumarins, a glycoside, was detected in the butanoic and methanolic extract of leaves and stems of the extract. In another qualitative study, a significant presence of coumarins and quinones and a moderate presence of saponins in the methanolic stem extract of *P. afra* was detected [9]. Other glycosides that have been found present in *P. afra* extract include cardiac glycosides, quinolones, and quinones [9,11].

Tannins

Tannins are polyphenolic biomolecules that are mostly found in fruits and vegetables. They can alleviate neurodegenerative illnesses by reducing oxidative stress, inflammation, abnormal protein buildup, and ameliorate mitochondrial dysfunction [27]. In another study, Gerzson and colleagues demonstrated the neuroprotective effects of tannin-rich extract in a streptozotocin-induced rat Alzheimer's disease model [28]. The study reported that tannic acid improved memory impairment, reduced brain acetylcholinesterase activity and suppressed oxidative stress by decreasing lipid peroxidation levels and increasing the GSH levels and SOD activity in the rat hippocampus. Adversely, only a study of Tabassum and co-workers [10] demonstrated the presence of tannins in the n-hexane extract of *P. afra.*

Alkaloids

Alkaloids are natural organic compounds with heterocyclic nitrogen atoms. Several studies have shown the presence of alkaloids in *P. afra* extracts. Plant alkaloids have various pharmacological activities such as anti-microbial, anti-cancer, analgesic, hypoglycemic, and antimalarial [17]. The methanolic extracts of *P. afra* have been reported to contain piperine, an alkaloids, identified using Gas Chromatography-Mass Spectroscopy (GC–MS) [17].

Vitamins

P. afra has been found to contain various amounts of vitamins. A study to determine the nutritional value of *P. afra* found significantly high quantities of ascorbic acid (vitamin C) (35.26 mg/100 g) in fresh *P. afra* leaves [18]. In another phytochemical quantification study, vitamin E was found to be one of the dominant compounds in the n-hexane extracts of *P. afra* [17].

Fatty acids and other phytochemical classes

The GC–MS analysis of *P. afra* extract revealed fatty acid as one of the dominant compounds of this plant. Some of the fatty acids which were identified as the major compounds in the n-hexane extract of *P. afra* were hexadecanoic acid, butyl ester, dichloroacetic acid, methyl hexadecanoate, Terephthalic acid, Dodecanoic acid, Tetradecanoic acid, 3-Hydroxyprop-2-enoic acid, 3-(3,4-Dimethoxyphenyl) prop-2-enoic acid, Methyl hexadecanoate, 8, and 11-Octadecadienoic acid [10,17]. N-hexadecanoic acid has been reported to possess nematicide, antioxidant and hypo-cholesterolemic properties [29]. Researchers have also reported octadecadienoic acid to possess anti-inflammatory, anti-cancer, hypocholesterolemic and hepatoprotective properties [30]. Table 3 provides a summary of bioactive compounds identified in *P. afra* extracts.

Biological activities of *Portulacaria afra*

Table 4 shows a summary of the pharmacological effects of *P. afra* extracts.

Antioxidant activities

Antioxidants significantly delay or prevent the oxidation of oxidizable substrates when present in lower concentrations than the substrate. The antioxidant activities of plants have received a lot of attention because increasing oxidative stress has been identified as a primary cause in the genesis and progression of various life-threatening diseases. The antioxidant activities of different parts *P. afra* have been reported. Khanyile and co-workers [53], reported high free radical scavenging potentials antioxidant activity of the methanolic extract of the leave using 2, 2-diphenyl-1- picrylhydrazyl (DPPH) and 2, 2′-azino-bis-3-ethylbenzothiazoline-6- sulfonic acid (ABTS) with reported IC_{50} values of 260 μg/mL and 250 μg/mL respectively. However, the acetone extracts of the leaves as reported by Olaokune and colleagues [4] displayed a higher antioxidant activity with an IC_{50} value of 32.05 μg/mL.

Conversely, the roots also exhibited scavenging power. The methanolic root extract showed a DPPH scavenging activity (IC_{50}= 390 μg/mL) while the hexane extract demonstrated an IC_{50} value of 1400.83 μg/mL [11]. In contrast, the leaves of *P. afra* demonstrated the best antioxidant activities compared to the roots. However, the antioxidant activity of the roots or the whole plant has not been determined.

Table 3
Identified bioactive compounds of *Portulacaria afra*.

Chemical Constituent	Molecular formula	Biological activities	Reference
Phenolic acids			
3-Methyl-4-propan-2-ylphenol	$C_{10}H_{14}O$	Anti-microbial, antioxidant, anti-tumor, antifungal	[17]
3-Allyl-6-methoxyphenol	CH_3CH_2OH	Anti-bacterial, antioxidant and anti-apoptotic	[10]
Acetic acid;2,4-ditert-butylphenol	$C_{16}H_{26}O_3$	Antioxidant, anticancer	[17,31]
2,6-Dimethoxy-4-[(E)-prop-1-enyl] phenol	$C_9H_{12}O_3$	Anti-bacterial, antioxidant and anti-apoptotic	[17]
Phenol, 2, 4-bis (1, 1-dimethyl ethyl)	$C_{17}H_{30}$	Anti-microbial, antioxidant, anti-tumor, antifungal	[17]
Essential oils/fatty acid			
Dodecanoic acid	$C_{12}H_24O_2$	Anti-bacterial, antioxidant and anti-apoptotic	[32,33]
Hexanedioic acid	$C_6H_{10}O_4$	Anti-bacterial	[34]
Terephthalic acid	$C_6H_4(COOH)_2$	Anti-cancer; antioxidant	[35,36]
Tetradecanoic acid	$C_{14}H_{28}O_2$	Hypoglycaemic; antiviral	[37,38]
3-Hydroxyprop-2-enoic acid	C_3H_4O	Anti-diabetic	[39]
Methyl hexadecanoate	$C_{17}H_{34}O_2$	Antioxidant, anti-inflammatory, anti-hyperlipidaemic, anti-microbial	[40]
8, 11-Octadecadienoic acid,	$C_{18}H_{32}O_2$	Antioxidant, anti-inflammatory, anti-microbial	[41]
Hexadecenoic acid	$C_6H_{10}O_4$	Antioxidants, antifungal, nematocidal, hypocholesterolaemia, anti-inflammatory	[42–44]
Alkaloids			
(2E,4E)−5-(1,3-Benzodioxol-5-yl)−1-piperidin-1-ylpenta-2,4-dien-1-one	$C_{17}H_{19}NO_3$ (alkaloid)	Anti-diabetic, anti-diarrheal, antioxidant, anti-bacterial, and anti-parasitic	[45]
Methyl octadecanoate	$C_{19}H_{38}O_2$	Antioxidant, hypocholesterolemic,	[46]
Vitamins			
Alpha-tocopherol	$C_{29}H_{50}O_2$	Anti-glycation and Antioxidant activity	[44,47]
Vitamin C	$C_6H_8O_6$	Antioxidant	[18]
Terpenoids			
Lupeol	$C_{30}H_{50}O$	Neuroprotective, Antioxidant	[48]
Other compounds			
Hexadecanoic acid	$C_{16}H_{32}O_2$	Anti-inflammatory	[49]
Phenol, 2, 4-bis (1, 1-dimethyl ethyl)	$C_{14}H_{22}O$	Antioxidant, anti-microbial	[50]
1-Hexadecene	$C_{16}H_{32}$	Anti-inflammatory, antioxidant; analgesic	[51]
1,3-Bis(trimethylsilyl)benzene	$C_{12}H_{22}Si_2$	Anti-microbial, antioxidant	[52]

Table 4
Summary of the pharmacological effects of *P. afra* extracts.

Plant extract	Method	Outcome	Reference
Antioxidant activity			
Methanolic root	DPPH and hydrogen peroxide scavenging assays.	High antioxidant activity (IC_{50}=0.39)	[11]
Hexane leaf	DPPH and hydrogen peroxide scavenging assays.	Hexane leaf extract (IC_{50}= 14.83)	[11]
Ethyl acetate root	DPPH free radical assay, hydrogen peroxide scavenging (H_2O_2) and metal chelating activity assay.	Ethyl acetate root extracts exhibited the strongest hydrogen peroxide scavenging activity compared to the other extracts.	[9]
Aqueous stem	DPPH radical.assay	Aqueous stem extracts showed the highest antioxidant activity against DPPH radicals.	[9]
Aqueous root	Aqueous and n-h metal chelating ability.	Aqueous and n-hexane root extracts displayed the strongest metal chelating ability.	[9]
Methanol whole plant	DPPH scavenging activity, TAC, and TRP.	IC_{50} value of 30.23 ± 0.49 μg/mL chloroform extract showed the minimum IC_{50} value of 34.42 ± 0.61 μg/mL	[4]
Methanolic whole plant	ABTS (2,2 azinobis 3-ethylbenothiazoline-6-sulfonic acid)	The extract showed a high antioxidant potential through (93.16 ± 0.05 mg TE /g dry extract)	[17]
Methanolic whole plant	ferric reducing antioxidant power (FRAP)	Significantly high antioxidant potential (80.45 ± 0.20 6 mg TE/g dry extract).	[17]
	cupric reducing antioxidant capacity (CUPRAC)	Significantly high antioxidant potential (90.88 ± 0.67 mg TE /g dry extract)	[17]
Acetone /leaves	Antioxidant activity (DPPH)	The *P. afra* extract exhibited the weakest DPPH radical scavenging ability with an IC_{50} value of 32.05 ± 3.89 μg/mL.	[4]
Glucose utilisation activity			
Acetone/leaves	*P. afra*, extracts on the glucose utilisation activities of C_2C_{12} muscle cells and 3T3-L1 adipocytes	The glucose utilisation activity of the C_2C_{12} muscle cells by the extract of *P. afra* was 0.40%, at the highest concentration of 500 μg/ml.	[4]
Anti-bacterial Activity			
Methanolic/ stem	Agar-well diffusion assay was used against *Staphylococcus aureus* and *E. coli*	The methanolic and hot water stem extracts displayed the largest inhibition zone (20 mm) against E. coli.	[11]
Aqueous/stem	Agar-well diffusion assay was used to determine the anti-bacterial activities of the leaves, stems, and roots of *P. afra* against *Staphylococcus aureus* and *E. coli*	The methanolic and hot water stem extracts displayed the largest inhibition zone (20 mm) against E. coli.	[11]
Aqueous root	Agar-well diffusion assay where plant extracts were tested against gram-positive *Staphylococcus aureus* gram-negative *E. coli* and gram-positive *streptomyces griseus*	The inhibition zones ranged from 13 to 24 mm for plant extracts.	[9]
Inflammatory activity			
Acetone/ leaves	5-lipoxygenase activity	5-lipoxygenase activity with an IC_{50} value of 107.26 ±5.63 μg/ml	[4]
Methanol whole plant	Carrageenan-induced paw oedema *in vivo* in Wistar albino rats	At the 3rd and 4th hour, percentage inhibition was observed in the range of 51.63% to 57.16 %	[17]
Methanol whole plant	Denaturation test	C_{50} value of 475.23 ± 3.25 μg/mL	[17]
Analgesic activity			
Methanol whole plant	*In vivo* (tail-immersion method) in Wistar albino rats	The treated groups showed significant anti-nociceptive effects at 200 mg/kg and 400 mg/kg (22.24 ± 0.090	[17]
Methanol whole plant	tail immersion test, hot plate method, and acetic acid-induced writhing test.	The *P. afra*-treated groups showed significant anti-nociceptive effects at 200 mg/kg and 400 mg/kg respectively, compared to the control group.	[17]

Anti-inflammatory activity

Inflammation is regarded as one of the key factors for the development of several diseases including cancer, cardiovascular disease, diabetes, and CNS-related diseases such as depression and Parkinson's disease [54–57]; hence, anti-inflammatory agents could provide a lead way to attenuate these inflammatory diseases. Over the years, natural products, particularly medicinal plants, have been proven to demonstrate anti-inflammatory potential.

Anti-inflammatory activities of *P. afra* have been reported in both *in vitro* and *in vivo* experimental models. The *P. afra* leaves methanolic extract inhibited the heat-induced denaturation of BSA in a dose-dependent manner compared to the standard, indomethacin indicating an anti-inflammatory activity [10]. Furthermore, the methanolic leaf extract demonstrated a dose-dependent reduction in carrageenan-induced paw oedema after 4 hours at 100, 200, and 400 mg/kg doses in albino rats [10] However, the anti-inflammatory activity of roots or whole plants has not been investigated.

Acetylcholinesterase inhibition activity

Acetylcholinesterase (AChE) inhibitors are currently an option for treating neurodegenerative diseases like Alzheimer's [58]. *P. afra* has displayed inhibitory activities against the two enzymes in the brain responsible for the breakdown of Acetylcholine-Cholinesterase (AChE) and Butyryl Cholinesterase (BChE). Tabassum and colleagues [10,17] investigated the

chloroform, butanol, and methanol-extracted leaves of *P. afra* for their acetylcholinesterase and butrylcholinesterase activity. The chloroform and butanol extract showed a higher percentage of inhibition of both enzymes than the methanolic extract when compared to the standard galantamine.

Anti-diabetic activity

In a study to determine the glucose utilisation activities of *P. afra* extracts, Oyinlola and colleagues investigated the effect of *P. afra* extracts on the glucose utilisation activities of C_2C_{12} muscle cells and 3T3-L1 adipocytes [4]. Their findings revealed that the acetone leaf extracts of *P. afra* enhanced the glucose utilisation activities of the muscle and fat cells in a dose-dependent manner. In another study, to assess the anti-diabetic potency of *P. afra*, the extracts were tested for their alpha-amylase and α-glucosidase inhibitory effects. Compared to the hydro-methanolic and chloroform extract, the *n*-hexane extract was the most active against both the tested enzymes with IC_{50} values of 0.6 mg/ml (against α-glucosidase) and 0.56 mg/ml (against α-amylase), followed by the hydro-methanolic extract and chloroform fraction [10]. In another study, *P. afra* leaf, stem and root aqueous extracts showed strong α-amylase inhibitory activity against the tested enzyme [59].

Analgesic activity

A recent study evaluated the methanolic leaf extract of *P. afra* for central and analgesic effects using rat pain models. The hot plate, tail immersion, and acetic acid-induced writhing method evaluated the analgesic potential in albino Wistar rats. The hot plate and tail immersion tests are sensitive acute pain tests used to determine analgesic responses, while the abdominal writhing test is used to investigate peripheral action [60]. The extract showed a significant, dose-dependent inhibition of nociception in the three models of pain used [17]. These findings justify the traditional use of *P. afra* leaf extract as a pain killer in the treatment of wounds and inflammatory diseases [5]

Anti-bacterial activity

The crude aqueous and methanolic leaf and stem extracts of *P. afra* at 25 mg/mL have demonstrated anti-bacterial activity against two bacterial strains*, E. coli* and *S. aureus* [11].. The anti-bacterial ability of *P. afra* leaf, root, and stem extract was also found against *Escherichia coli, Staphylococcus aureus* and *Streptomyces* [9]. In another study, the silver nanoparticle biosynthesised using leaf extracts of *P. afra* exhibited anti-bacterial activity against *Bacillus subtilis, E. coli, Neisseria gonorrhoeae, Pseudomonas aeruginosa, Staphylococcus aureus*, and *Streptococcus faecalis* [16].

Anti-cancer activity

A study evaluated the anti-cancer effects of silver nanoparticles synthesised using the methanolic leaf extract of *P. afra* in the human breast cancer cell line (MCF 7). The *P. afra* extract suppressed the cell viability of the tested cell line in a dose-dependent manner [16, 53]. In another study, the anti-tumor activity of *P. afra* extract was evaluated by testing its cytotoxic effects using the brine shrimp lethality assay [53].

Conclusions and future perspectives

This review provides a comprehensive overview of the phytochemical composition, ethnopharmacological uses and pharmacological activities of *Portulacaria afra (P. afra)*. Current scientific evidence supports the pharmacodynamic potential of *P. afra* extracts, aligning with its traditional medicinal and folkloric use. The reviewed literature highlights a range of pharmacological properties including antioxidant, anti-inflammatory, analgesic, anti-microbial, anti-cancer, and hypoglycaemic effects. However, despite these promising findings, the majority of pharmacological studies have been limited to *in vitro* experiments with no preclinical or clinical investigations conducted to elucidate the therapeutic mechanisms of the plant. This gap significantly hinders the translation of its medicinal potential to clinical application.

To advance the therapeutic understanding of *P. afra*, it is necessary to conduct further *in vitro* and *in vivo* studies. These should focus on pre-clinical animal models to explore its mechanisms of action and safety profiles, which could lay the foundation for future clinical trials. Additionally, rather than identifying the broad bioactive phytochemical classes, efforts will be directed toward characterising specific bioactive compounds that are responsible for the observed pharmacological activities. This approach would enhance the precision and potential applicability of *P. afra* as a complementary and alternative therapy in modern medical treatments.

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Declaration of competing interest

The authors declare no conflicts of interest.

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Data availability statement

The data presented in this study are available in the article.

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