

REVIEW

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# A review of the ethnomedicinal, antimicrobial, and phytochemical properties of *Musa paradisiaca* (plantain)

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## Abstract

**Background:** More people—in both developing and developed countries—now use, and are favourably disposed to, traditional medicine. *Musa paradisiaca* (plantain) is used extensively in traditional medicine across continents. In this review, we investigated the scientific justification of this extensive usage.

**Main body:** Generally, several studies validate usage in infectious diseases, but limited antiviral and in vivo reports exist. The mechanistic elicitation of antimicrobial activity has similarly not been ascertained. Contrarily, data abound from rigorous studies on physiological conditions. Activity across categories is tied to the potent phytosterols duo of stigmasterol and  $\beta$ -sitosterol; and the triterpenes viz. cycloeucalenone, 24-methylene-cycloartanol, and 31-norcyclolaudenone; present in plantain. Toxicity studies, while finite, suggest general safety and tolerance.

**Conclusions:** Findings in the studies reviewed projects plantain as a veritable source for drug bioprospecting that will be of benefit to scientific research and pharmaceutical industries.

**Keywords:** *Musa paradisiaca*, Plantain, Peel, Fruit, Antimicrobial, Phytochemicals, Extract, Medicinal, Activity

## Background

The success of antibiotics against disease-causing microbes is one of the modern medicine's greatest achievements. Since the discovery of the first antibiotic from nature (mycophenolic acid) in 1893 by Bartolomeo Gosio from *Penicillium glaucum* (*P. brevicompactum*); synthesis of Salvarsan (arsphenamine) by Paul Ehrlich; and ultimately the serendipitous discovery of penicillin from *Penicillium chrysogenum* (previously *P. notatum*) by Alexander Fleming in 1928 (Nicolaou and Rigol 2018), healthcare delivery has significantly improved. An off-target effect of these discoveries is that it also stimulated search for both prophylaxis and therapeutic agents. But before orthodox medicine, traditional medicine,

primarily herbal medicine, held sway world over (Alber-tyn et al. 2015; Hosseinzadeh et al. 2015; Jaiswal et al. 2016; Li and Weng 2017). Traditional medicine, once regarded as quackery (Verpoorte 2017), and treated with scorn (Thomford et al. 2018), however, is making a resurgence (Amaeze et al. 2018) plausibly due to cost, limited and restricted access to orthodox treatment (Leonti and Casu 2013), antibiotic resistance (Blair et al. 2015), and perceived safety (Zhang et al. 2015) of herbal medicine due to its natural origin. An estimated 80% of population of the world utilise herbal medicines (Chatfield et al. 2018) with the sector valued at USD 100 billion (Zhang et al. 2015). This is testament of the renewed acceptance herbal medicine is enjoying.

Herbal medicine, in some nomenclature, also called phytomedicine (Bruno et al. 2018; Chatfield et al. 2018), relies on medicinal plants (Li and Weng 2017), herbs (Thomford et al. 2018), roots (Chu et al. 2018), and fruits

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(Aune et al. 2017; Chatfield et al. 2018; Chu et al. 2018; Kipkore et al. 2014; Ożarowski et al. 2018; Shakib et al. 2019). While herbs, roots, their stems, rhizome, and barks are popular in traditional medicine, fruits and plants have a long history of application too (Kipkore et al. 2014; Nirumand et al. 2018). Medicinal fruits, also referred to as functional foods or nutraceuticals due to their perceived health benefit (Gul et al. 2016; Patiño-Rodríguez et al. 2019), serve a dual role of dietary/nutritional and curative function (Pereira and Maraschin 2015). One of such fruit is plantain (*Musa paradisiaca*). This review highlights the antimicrobial, traditional, medicinal, along with the phytochemical constitution, usage of plantain while identifying current gaps.

### Description, distribution, and traditional uses

*Musa paradisiaca* (common name: plantain) is an herbaceous (Arun et al. 2018; Ugbogu et al. 2018), perennial, monocotyledonous plant (Singh et al. 2016) belonging to the genus *Musa* along with (dessert) bananas (*M. sapientum*) (Pereira and Maraschin 2015) in the family Musaceae (Ajiboye et al. 2018; Oyeyinka and Afolayan 2019; Ugbogu et al. 2018). These two are hybrids of *M. acuminata* (A) and *M. balbisiana* (B) giving them a polyploid nature with plantains containing majorly the genomes AAB, ABB, and BBB (Pereira and Maraschin 2015; Singh et al. 2016). The abaxial bract surface of plantains lacks papillae just like the adaxial epidermis which lacks calcium oxalate crystals that, otherwise, is present in bananas (Pereira and Maraschin 2015).

The plant is a tropical (Ajiboye et al. 2018; Imam and Akter 2011; Pereira and Maraschin 2015; Ugbogu et al. 2018) tree-like herb (Bagavan et al. 2011; Imam and Akter 2011; Lakshmi et al. 2015) that can grow to a height between 3 m (Imam and Akter 2011; Vilhena et al. 2019) and 15 m with an aerial pseudostem and submerged rhizome (Lakshmi et al. 2015) producing the large, pulpy, and starchy fruit (plantain) (Pereira and Maraschin 2015) with an elongated shape (Imam and Akter 2011) between 8 and 13 cm long (Mathew and Negi 2017).

While the plant is believed to be native to Southeast Asia, it is now cultivated extensively across both tropical and subtropical climates (Pelissari et al. 2012; Vu et al. 2018) including Nigeria (Eleazu et al. 2013; Tanee and Albert 2013; Yakubu et al. 2015) which ranks highest in West African production and sixth globally at 2.4 metric tonnes (Ekpete et al. 2017), while Central Africa is recognised for its great diversity of unique cultivars (Tsamo et al. 2014). In 2012 and 2013, global production stood at 118 mt (Sartori and Menegalli 2016). This huge production is a testament of the importance of plantain as an important food crop coming behind only rice, wheat, and maize (Shamla and Nisha 2017) while being the most

produced fruit accounting for a whopping 16.8% of fruits produced globally (Vu et al. 2018).

Apart from hybrids, cultivars are generally classified as French or Horn on the basis of the presence or otherwise of a male bud at maturity (Tsamo et al. 2015). The fruit, a pulp, differing from bananas in being starchy rather than sweet-tasting (Jiménez-Martínez et al. 2017), is a rich source of diverse nutrients and phytochemicals (Bennett et al. 2010; Jiménez-Martínez et al. 2017; Oyeyinka and Afolayan 2019; Pereira and Maraschin 2015; Shamla and Nisha 2017; Tsamo et al. 2015).

Thus, plantain can serve the dual purpose of dietary/nutritional and therapeutic roles. Apart from the pulp, the peel, both ripe and unripe, which represents approximately 38% of the fruit in weight (Agama-Acevedo et al. 2016) similarly, is a phytochemical and nutrient repository (Behiry et al. 2019; Oyeyinka and Afolayan 2019; Silva et al. 2014) with further application as livestock feed and compost (Agama-Acevedo et al. 2016), and in biorefinery (Martínez-Ruano et al. 2018). Other parts of the plant, such as leaf, shoot, root, fruit, seed, inflorescence, and flower, are also receiving scientific attention (Kapadia et al. 2015; Correa et al. 2016; Lavanya et al. 2016; Mathew and Negi 2017).

These characteristics influence the use of plantain in folk medicine to cure both infectious and non-infectious diseases and wound healing (Amutha and Selvakumari 2016; Pereira and Maraschin 2015; Shodehinde and Oboh 2013; Vu et al. 2018).

### Antimicrobial properties

In recognition of the role and importance of herbal medicine, World Health Organisation (WHO) has over the years carried out a number of strategic plans and passed resolutions aimed at improving the efficacy and quality of drugs of plant origin. The outcome of these has led to increased scientific inquiry into the basis and justification of their traditional uses (WHO 2013). One of the products of this endeavour is that since the release of the WHO's first series of Traditional Medicine Strategy (2002–2005), significant advances have been recorded in the scientific understanding of traditional and complementary medicine. This has had the knock-on effect of initiation and development of technical standards and guidelines for organised herbal health service delivery (WHO 2013).

There are a number of reports on antimicrobial activities of plantain (*M. paradisiaca*), and several organisms including fungi and bacteria with parasites and viruses enjoying lesser attention have been used as test organisms. Asoso et al. (2016) reported the antimicrobial activities of plantain peel and fruit extracts against *Escherichia coli*, *E. coli* ATCC 35218, *Staphylococcus aureus*, *S. aureus*

ATCC 25923, *Salmonella typhi*, *Salmonella typhi* ATCC 22648, *Salmonella typhi* ATCC 23456, *Shigella dysenteriae* ATCC 24162, *Klebsiella pneumonia* ATCC 34089, and *Bacillus subtilis* ATCC 21332 using agar well diffusion technique. Ethanolic extract of the peels had minimum inhibitory concentration (MIC) values between 150 and 200 mg/mL with the least being against *S. aureus* 25923 ATCC and the highest against *Salmonella typhi* 22648 ATCC and *Klebsiella pneumonia* 34089 ATCC. Ethanolic extracts of fruits had an MIC range of 200 and 300 mg/mL. Methanolic extract of peels on the other hand ranged from 100 mg/mL to 200 mg/mL, while methanolic extract of fruit yielded an MIC of 150 mg/mL and 250 mg/mL. Extracts of acetone from both peels and fruits had no activity against the test isolates. While activity was recorded, discrimination was not observed on the basis of cell wall Gram reaction suggesting that the mechanism of activity was by a route other cell wall lysis. The opportunistic skin pathogens, *Propionibacterium acnes* (Fitz-Gibbon et al. 2013; Perry and Lambert 2011) now known as *Cutibacterium acnes* (Dréno et al. 2018) and *S. epidermidis* (Taha et al. 2018), have been shown to be susceptible ethanolic extract of peel powder which makes it a potential antibacterial cosmetic agent. This potential usage is reinforced by Prakash et al. (2017) who reported inhibitory effect against *Aspergillus niger* now implicated in cases of *Tinea capitis* (Chokoeva et al. 2016).

In addition to bacteria, Jawla et al. (2012) challenged fungi with ethanolic and ethanolic and aqueous (1:1) extracts of *M. paradisiaca* flowers using the micro-dilution assay with MIC values of 5.62–25.81 µg/mL and 7.61–31.58 µg/mL, respectively. *Candida albicans* MTCC-2661 had an MIC of 6.49 and 7.61 µg/mL for ethanolic and ethanolic and aqueous extracts, respectively. *C. albicans* MTCC-183 had marginally higher values at 8.62 µg/mL for ethanolic extracts and 9.88 µg/mL for ethanolic and aqueous (1:1) extracts. Bacterial isolates *Pseudomonas aeruginosa* ATCC-9027, *B. subtilis* MTCC-121, and *B. cereus* MTCC-430 had ethanolic MIC of 5.62, 6.82, and 7.95 µg/mL, while peak ethanolic MIC was observed with *Salmonella typhimurium* MTCC-98. *E. coli* MTCC-443 yielded peak MIC in ethanolic and aqueous (1:1) extracts with *Streptococcus pneumoniae* MTCC-2672 ranking below it at 24.86 µg/mL marginally ahead of *Proteus mirabilis* MTCC-1429 with 22.13 µg/mL. Generally, ethanolic extracts were active at lower concentration relative to ethanolic and aqueous (1:1) extracts an observation we attribute to a dilution effect of the water within the ethanolic and aqueous (1:1) extract. The authors went on to evaluate the acute and short-term toxicity of extract on albino Wistar rat models with results indicating no toxicity and morbidity.

The limitation in this study, however, is that phytochemical assay was not done; thus, activity cannot be attributed to any phytochemical group which Ahmad et al. (2015) reported on. The authors reported the presence of glycosides, flavonoids, phenols, and saponins in ethanolic and methanolic extracts obtained via cold extraction. The aqueous extracts, however, lacked saponins.

Proximate analysis of flesh, peel, and peel aqueous extract by Oyeyinka and Afolayan (2019) reports the presence of fat, moisture, carbohydrates (which dominate at around 68%), fibre, and minerals such as potassium, nitrogen, phosphorus, calcium, sodium, and magnesium in that order of quantity with trace elements such as zinc, copper, iron, and manganese present in minute quantities. Significantly, the graduation of quantity followed the same pattern in the pulp, peel, and peel extracts. Antinutrients, within WHO limits, such as phytate and oxalate were also present. This study proves the diversity of phytochemicals and nutrients inherent in plantain justifying its broad usage. A concern, however, is that the pulp is reported to severely interfere with absorption of quinolones with co-administration limiting the activity of ciprofloxacin against *E. coli* (Nwafor et al. 2003). This raises concern about drug interaction and influencing dynamics for which currently few, or no, data exist.

Chabuck et al. (2013) reported the antimicrobial effect of aqueous plantain peel extract. Aqueous extract of fresh yellow plantain peel was used to challenge two Gram-positive (*S. aureus* and *S. pyogenes*) and four Gram-negative bacteria (*Enterococcus aerogenes*, *Klebsiella pneumoniae*, *E. coli*, and *Moraxella catarrhalis*) and a yeast isolate (*Candida albicans*). The aqueous extract of fresh plantain peel showed various inhibitory effects against the microbial isolates having the highest inhibitory effect against *M. catarrhalis* and *S. aureus*, followed by *S. pyogenes*, *E. aerogenes*, and *K. pneumoniae*. However, no effect against *E. coli* and *Candida albicans* was observed implying intrinsic resistance.

Kapadia et al. (2015) evaluated the antimicrobial activity of alcoholic extract of plantain peel extract on the anaerobic Gram-negative periodontal pathogens *Porphyromonas gingivalis* and *Aggregatibacter actinomycetemcomitans*. The minimum inhibitory concentration, assessed using serial broth dilution method, showed that both *P. gingivalis* and *A. actinomycetemcomitans* had an MIC of 31.25 µg/mL. The study, however, did not screen for phytochemical constituents nor run assays to determine mechanism of activity; thus, it is difficult to attribute an inhibitory pathway to the observation. However, observed activity can be attributed to the concerted inhibition by phytochemicals and ethanol which is inherently antimicrobial.

The antimicrobial activity of hexane, ethyl acetate, and methanol extracts of leaves of some banana species, including *M. paradisiaca*, was reported by Karupiah and Mustafa (2013). To ascertain their antibacterial activities, *E. coli*, *P. aeruginosa*, *Citrobacter* species, and other bacteria which have been implicated in hospital-acquired infections (Mohammed et al. 2016; Tilahun et al. 2012; Zhang et al. 2017), were used as test organisms. The study revealed that ethyl acetate extracts were more potent than methanolic extract which in turn was better than hexane extract. Ethyl acetate extracts, however, had variable efficacy relative to chloramphenicol. *P. mirabilis* and *E. aerogenes* were resistant to hexane extracts. Significantly, the hexane extract had the highest MIC which ranged from 125.00 to 250.00 µg/mL followed by methanolic extract between 15.63 and 250.00 µg/mL with ethyl acetate ranking last between 15.63 and 125.00 µg/mL. Hexane extract had a minimum bactericidal concentration of 250.00 µg/mL, and ethyl acetate and methanolic extracts had a range between 31.25 and 250.00 µg/mL. The generalised trend of bactericidal concentration was *E. coli* < *P. aeruginosa* < *E. aerogenes* < *K. pneumoniae* < *P. mirabilis* < *S. flexneri* < *Citrobacter* sp. < *E. faecalis* < *S. aureus*. The authors attribute the activity observed to the presence of phenolic compounds, a theory valid from the results of their antioxidant activity which correlates directly. Significantly, *M. paradisiaca* had the most antioxidant activity with the order being *M. paradisiaca* > *M. acuminata* > *M. sapientum* > *M. troglodytarum*. The only limitation with this study is that some extracts needed relatively high concentration to achieve inhibition or bactericidal activity which will necessitate a toxicity study to establish safety. Asuquo and Udobi (2016) reported that aqueous extracted performed better than ethanolic extract with an acute toxicity LD<sub>50</sub> of 489.9 mg/kg, suggesting that an effective dose may be toxic. In a similar study, Amutha and Selvakumari (2016) report the MIC of methanolic stem extract as 0.5 mg/mL for *P. aeruginosa* and 1.0 mg/mL for *S. aureus* with inhibition zone (mm) ranking behind only gentamicin for *P. aeruginosa* and chloramphenicol and novobiocin for *S. aureus*.

Karadi et al. (2011) reported the in vitro antimicrobial activities of dichloromethane and methanol (1:1) extract of *M. paradisiaca* fruit peels against on *E. coli*, *S. aureus*, *B. subtilis*, *P. aeruginosa*, *C. albicans*, *C. tropicalis*, and *A. niger* using the agar well disc diffusion method. Results indicated that the extract of *M. paradisiaca* was more effective against the test isolates than the extract of *Cocos nucifera*.

Antifungal effects of plantain peel and stalk were examined by Okorondu et al. (2012) where *A. niger*, *A. oryzae*, and *Rhizopus stolonifer* were subjected to different concentrations (1.00, 0.50, 0.25, 0.125, 0.0625 mg/mL) of

methanolic and ethanolic extracts of the peel and stalk. *A. niger* was more sensitive to both the peel and stalk extracts followed by *A. oryzae* and then *R. stolonifer*. Methanolic extracts yielded better activity relative to the ethanolic extract. Across both solvents, degree of inhibition of stalk extracts was correlated with concentration with 0.125 mg/mL MIC for *A. niger*, 0.25 mg/mL for *A. oryzae*, and 0.5 mg/mL for *R. stolonifera*. For peel extract, a different trend was observed with a methanolic MIC of 0.25 mg/mL *A. niger* and *A. oryzae* and 0.125 mg/mL for *R. stolonifera*. *A. niger* was 0.0625 mg/mL, 0.125 mg/mL for *A. oryzae*, and 0.25 mg/mL for *R. stolonifera*. MIC for ethanolic extracts was pegged at 0.25 mg/mL for all isolates.

The test isolates are known food spoilage agents (dos Santos et al. 2012); thus, the results of the study suggest that the extracts of plantain peel and stalk, at appropriate concentrations, can be used in food preservation to prevent growth and spoilage by those spoilage fungi. A concern from the study, however, is that the authors identified the presence of cyanide and hydrogen cyanide, along with some phytochemicals, which could be a hazard (Tran et al. 2019) due to the associated adverse effects they are known to cause. The study also did not report on toxicity; thus, the safety of active concentrations—which is essential since its application is to be in food—cannot be ascertained.

While the majority of studies focus on extracts, Abdel Ghany et al. (2019), in an holistic study, investigated the activity of exudates of *M. paradisiaca* pseudostem against bacteria, fungi, and viruses. The exudate, also referred to as sap (Abdel Ghany et al. 2019) or mucilage (Galloway et al. 2020) sourced from conducting tissues (Zimmermann et al. 2013), is a viscous liquid, rich in organic molecules, capable of mediating plant physical and physiological responses (Galloway et al. 2020; Naveed et al. 2017) often, but not necessarily, produced in response to injury (Abdel Ghany et al. 2019; Zimmermann et al. 2013). Alkaloid, flavonoid, cardiac glycoside, anthraquinone, and phlobatannins were present in both methanolic and aqueous extracts of the exudates with only cardiac glycoside being absent in the aqueous extract. The exudate inhibited *S. aureus* and *E. coli* at low concentrations of 25 µL/mL and 50 µL/mL but *Lactobacillus acidophilus*, and *P. aeruginosa* required the relatively higher concentrations of 100 µL/mL and 200 µL/mL for inhibition. The extract performed below the reference antibiotic ciprofloxacin. The authors, in one of the rare available reports on viruses, reported weak antiviral activity against hepatitis A virus (HAV-10) and significantly no activity against herpes simplex virus (HSV-1). Antifungal effect against both dermatophytes (*Microsporum canis* RCMB 0834 and *Trichophyton*

mentagrophytes RCMB 092) and opportunistic (*Cryptococcus neoformans* RCMB 0049001; *A. fumigatus* RCMB 002008; *C. tropicalis* RCMB 005004 (1); and *C. albicans* RCMB 005003) showed that the exudate had no activity. An observation the authors noted is corroborated by Onyema et al. (2016) and Priya et al. (2014).

Following the increased attention plant-synthesised nanoparticles are receiving, Vijayakumar et al. (2017) reported the antibacterial activity of gold nanoparticles synthesised from the aqueous peel extract of plantain against multidrug-resistant biofilm community of *E. faecalis* MTCC 35550. Like other reports, the authors reported the presence of quinones, glycosides, tannins, phenols, flavonoids, essential oils, steroids, and phytosteroids which singly or collectively serves as reducing agent to chloroauric acid ( $\text{HAuCl}_4$ ), thus mediating the synthesis of gold nanoparticles. At a dose-dependent rate, the agent inhibited the biofilm. Beyond 100  $\mu\text{g}/\text{ml}$ , complete inhibition was reported as evidenced by the fragmentation of biofilm architecture. Relative to the nanoparticle, the  $\text{HAuCl}_4$  control had no activity. The authors putatively attribute activity to the ability of the nanoparticle to impair and prevent the synthesis of exopolysaccharide essential for biofilm formation. The activity of silver nanoparticles synthesised from plantain bract extract has similarly been reported as active against the plant pathogens *Xanthomonas campestris*, *Clavibacter michiganensis*, *P. syringae*, *Burkholderia glumae*, *Alternaria alternata*, *Sclerotinia sclerotiorum*, *Macrophomina phaseolina*, and *Botrytis cinerea* (Maruthai et al. 2018). The authors suggest that activity is attributable to the ability of the nanoparticle to induce oxidative stress, disrupt electron transport chain, and impede deoxyribonucleic acid (DNA) synthesis in bacteria, while antifungal activity is due to its ability to lysis cell membrane via membrane potential imbalance—due to the high degree of the nanoparticles' dispersion.

Accioly et al. (2012) reported the activity of *M. paradisiaca* (leaf) methanol 100%, hexane/chloroform (50:50), ethylacetate/methanol (50:50), and ethylacetate/methanol (90:10) crude extracts against amastigotes and promastigotes of *Leishmania chagasi*, the causative organism leishmaniasis for which the epidemiology in Nigeria (Adediran et al. 2016) and indeed sub-Sahara Africa is poorly documented (Sunyoto et al. 2018). The best activity against promastigotes was observed in ethylacetate/methanol (90:10) and methanol 100% at an inhibitory concentration (50%) ( $\text{IC}_{50}$ ) of 1.70 and 1.83  $\mu\text{g}/\text{mL}$ , respectively, while against amastigotes, ethylacetate/methanol (90:10) and hexane/chloroform (50:50) had the best inhibitory activity at 14.18 and 15.07  $\mu\text{g}/\text{mL}$ , respectively. Observed activity was ascribed to the phytosterols like stigmasterol and  $\beta$ -sitosterol known to proliferate the

activity of natural killer (NK) cells and T cells, alkaloids, tannins, anthocyanins, and phenolic compounds. This ascription is further reinforced by the infrared absorption bands of the hexane/chloroform (50:50) fraction peaked at hydrogen and C-13 which is signatory of stigmasterol and  $\beta$ -sitosterol. Zhang et al. (2012) reported the C-14 in cucumber and pumpkin stem exudates possessed activity. Another antiparasitic effect reported is anticoccidial activity. Anosa and Okoro (2011) report that at a dose-dependent rate, inhibition is observed with peak dose being 1000 mg/kg b.w. with no acute toxicity even at 4000 mg/kg b.w.

Silva et al. (2014) went further to evaluate, in vitro, the activity of three triterpenes (24-methylene-cycloartanol, cycloeucalenone, and 31-norcyclolaudenone) and a mixture of two sterols, namely stigmasterol and  $\beta$ -sitosterol, obtained, via column chromatography, from the ethanolic peel extract of unripe *M. paradisiaca* against *Leishmania infantum chagasi* promastigotes and amastigotes. Cycloeucalenone lacked activity, while the 24-methylene-cycloartanol, 31-norcyclolaudenone, and sterols exerted anti-promastigote effect with an effective concentration (50%) ( $\text{EC}_{50}$ ) of 16.55, 39.29, and 14.35  $\mu\text{g}/\text{mL}$ , respectively. Anti-amastigote  $\text{EC}_{50}$  of cycloeucalenone, 24-methylene-cycloartanol, and sterol mixtures was evaluated as 185, 98.75, and 126.5  $\mu\text{g}/\text{mL}$ , respectively. The individual activity of each of the sterols needs to be investigated to determine whether there is a synchronised or antagonistic activity in the current result. All the agents effected less toxicity to the mammalian LLC-MK2 and RAW264.7 cells relative to the standard drug pentamidine with the order being 24-methylene-cycloartanol < cycloeucalenone < 31-norcyclolaudenone < sterol mixture for RAW264.7 cell and 24-methylene-cycloartanol < 31-norcyclolaudenone < cycloeucalenone < sterol mixture for LLC-MK2, suggesting that 24-methylene-cycloartanol is the least toxic even though it is not the most efficacious. This implies that in vivo studies and dosing regimen are essential to build upon the current encouraging preliminary results. Table 1 summarises selected antimicrobial activity previously reported in the literature.

The broad spectrum of organisms susceptible to *M. paradisiaca*, its extracts, exudates, nanoparticles, and other scaffolds justify its utilisation in the management of diarrhoeal diseases. Putatively, our search identifies phytosterols (specifically stigmasterol and  $\beta$ -sitosterol) and the triterpenes, cycloeucalenone, 24-methylene-cycloartanol, and 31-norcyclolaudenone as the active metabolites mediating this broad range of activity. The structure of the compounds is provided in Fig. 1.

In addition to the antibiotic effect, it delayed the onset of diarrhoea; faecal water, its quantity, weight, and

**Table 1** Selected reports of antimicrobial applications of different plantain parts

Plant part	Extract	Test isolates	Assay technique	MIC/MBC/MFC/EC <sub>50</sub>	References
Peel and fruit	Ethanollic, methanolic	<i>Escherichia coli</i> , <i>E. coli</i> ATCC 35218, <i>Staphylococcus aureus</i> , <i>S. aureus</i> ATCC 25923, <i>Salmonella typhi</i> , <i>Salmonella typhi</i> ATCC 22648, <i>Salmonella typhi</i> ATCC 23456, <i>Shigella dysenteriae</i> ATCC 24162, <i>Klebsiella pneumoniae</i> ATCC 34089, <i>Bacillus subtilis</i> ATCC 21332	Agar well diffusion	100–300 mg/mL	Asoso et al. (2016)
Peel powder	Aqueous	<i>Aspergillus niger</i>	Agar well diffusion	Not determined	Prakash et al. (2017)
Flowers	Ethanollic and mixed ethanolic and aqueous (1:1)	<i>Candida albida</i> MTCC-2661, <i>C. albicans</i> MTCC-183, <i>Pseudomonas aeruginosa</i> ATCC-9027, <i>B. subtilis</i> MTCC-121, <i>B. cereus</i> MTCC-430, <i>S. typhimurium</i> MTCC-98, <i>E. coli</i> MTCC-443, <i>Streptococcus pneumoniae</i> MTCC-2672, <i>Proteus mirabilis</i> MTCC-1429	Microdilution	6.49–31.58 µg/mL	Jawla et al. (2012)
Peel	Aqueous	<i>S. aureus</i> , <i>S. pyogenes</i> , <i>Enterococcus aerogenes</i> , <i>K. pneumoniae</i> , <i>E. coli</i> , <i>Moraxella catarrhalis</i> , <i>Candida albicans</i>	Agar well diffusion	Not determined	Chabuck et al. (2013)
Peel	Alcoholic	<i>Porphyromonas gingivalis</i> and <i>Aggregatibacter actinomycetemcomitans</i>	Broth dilution	31.25 µg/mL	Kapadia et al. (2015)
Leaf	Hexane, ethyl acetate and methanolic	<i>E. coli</i> , <i>P. aeruginosa</i> and <i>Citrobacter</i> sp.	Agar well diffusion	MIC: 15.63–250 µg/mL; MBC: 31.25–250 µg/mL	Karupiah and Mustafa (2013)
Peels	Dichloromethane and methanol (1:1)	<i>E. coli</i> , <i>S. aureus</i> , <i>B. subtilis</i> , <i>P. aeruginosa</i> , <i>C. albicans</i> , <i>C. tropicalis</i> and <i>A. niger</i>	Aqueous	55–85 µL	Karadi et al. (2011)
Peel and stalk	Methanolic and ethanolic	<i>A. niger</i> , <i>A. oryzae</i> , and <i>Rhizopus stolonifer</i>	Poisoned plate technique	0.125–0.5 mg/mL	Okorundu et al. (2012)
Pseudostem exudates	Methanolic and aqueous	<i>S. aureus</i> , <i>E. coli</i> , <i>Lactobacillus acidophilus</i> , <i>P. aeruginosa</i> hepatitis A virus (HAV-10), and herpes simplex virus (HSV-1)	Agar well diffusion	25–200 µL/mL	Abdel Ghany et al. (2019)
Peel	Gold nanoparticles	<i>E. faecalis</i> MTCC 35550	Polystyrene plating	100 µg/mL	Vijayakumar et al. (2017)
Bract	Silver nanoparticles	<i>Xanthomonas campestris</i> , <i>Clavibacter michiganensis</i> , <i>P. syringae</i> , <i>Burkholderia glumae</i> , <i>Alternaria alternata</i> , <i>Sclerotinia sclerotiorum</i> , <i>Macrophomina phaseolina</i> , and <i>Botrytis cinerea</i>	Disc diffusion	Not determined	Maruthai et al. (2018)
Leaf	Methanolic, hexane/chloroform (50:50), ethylacetate/methanol (50:50), ethylacetate/methanol (90:10)	<i>Leishmania chagasi</i> (amastigotes and promastigotes)	3-[4,5-Dimethylthiazol-2-yl]-2,5-diphenyltetrazolium-bromide (MTT) assay	1.70–915.2 µg/mL	Accioly et al. (2012)
Peel	Ethanollic	<i>Leishmania infantum chagasi</i> (promastigotes and amastigotes)	(MTT) assay	10.38–532.8 µg/mL	Silva et al. (2014)

frequency; and improved electrolyte absorption (Yakubu et al. 2015). Since the antimicrobial activity exhibited by plantain is as a result of the embedded phytochemicals (Onyenekwe et al. 2013; Ehiowemwenguan et al. 2014), there is therefore a necessity to carry out extensive studies on how to maximally extract and process the useful phytochemicals into antimicrobials.

From these studies, empirical evidence of limited and, at other times, total (intrinsic) resistance of some test isolates suggests that the issue of antimicrobial resistance still exists. This lends credence to the claim (French 2010) that while abuse and misuse contribute significantly to antibiotic resistance, resistance is inherently an evolutionary survival scheme in the arsenal of microorganism; thus, the place of antibiotic pressure is significant only in speeding up the process. This creates a window for modification of agents into scaffolds to broaden the range, and thus efficacy, of available antimicrobials. The major variables influencing activity can have dynamic interaction (Fig. 2).

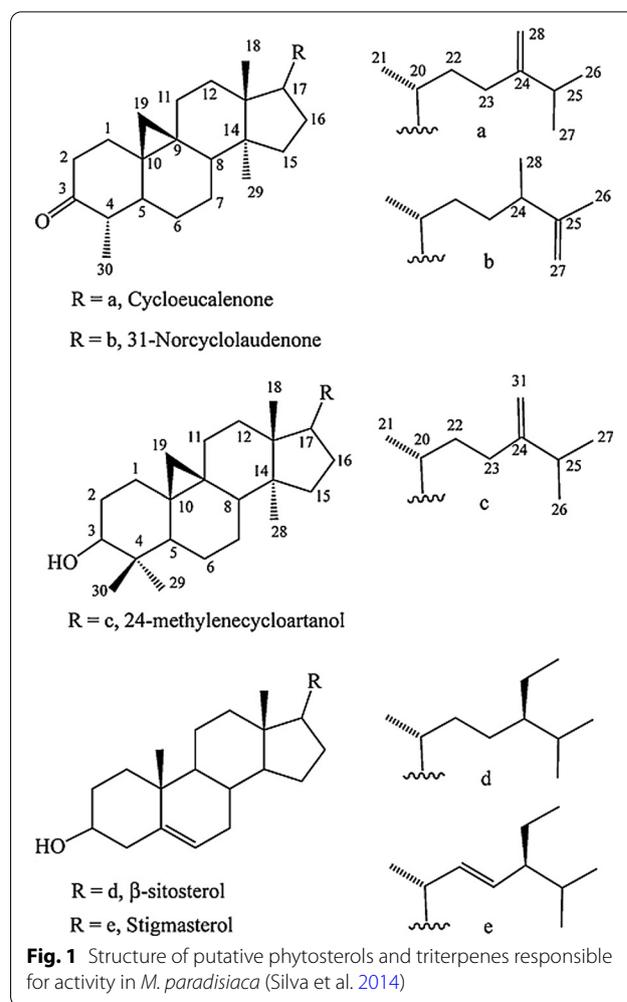
### Other medicinal properties

Beyond antimicrobial application, plantain is traditionally used for other purposes (Correa et al. 2016).

### Wound healing

A whopping 33.3% of traditional medicines are used in wound treatment and management majorly because of the accessibility, affordability, and safety (Accioly et al. 2012; Gebrehiwot et al. 2015). Traditionally, plantain is used in indigenous medicine, which the WHO estimates are used by 80% of the developed world's population (Asuquo and Udobi 2016), for wound healing (Amutha and Selvakumari 2016; Krishnan et al. 2014; Pereira and Maraschin 2015; Shodehinde and Oboh 2013) as a poultice (Agyare et al. 2009; Pereira and Maraschin 2015) which following the release of mediators of inflammation is followed by angiogenesis and fibroblast before it ends with the synthesis and remodelling of collagen fibres (Joshi et al. 2013; Murthy et al. 2013; Patil et al. 2012).

Consequently, it can be assumed that the phytochemical constituents of plantain can stimulate and mediate this process. Amutha and Selvakumari (2016) investigated this hypothesis using Wistar albino rat models inflict with red hot steel rod in hind limb region anaesthetised with ether. Treatment of the wound with methanolic extract of plantain stem resulted in faster wound healing relative to a control group treated with Vaseline. This was confirmed by comparing histopathological slides. This activity was attributed to the ability of the flavonoid content to, in addition to its antimicrobial activity, strengthen collagen fibres by increasing the fibrils' viability. The flavonoids, sterylacyl glycosides,



and sitoindosides I–IV which are present in *M. paradisiaca* with sitoindoside IV which is known to recruit and amplify peritoneal macrophages and the general ability of flavonoids to limit the peroxidation of lipids are assumed to enhance normal wound healing (Alam et al. 2011; Patil et al. 2012). The antioxidant content of plantain extracts such as apigenin, shogaol, myricetin, isorhaemnetin, capsaicin, luteolin, caffeic acid, p-hydroxybenzoic acid, quercetin, kaempferol, glycitein, and gingerol (Fongnzosie et al. 2017) which have been severally reported (Abdel Ghany et al. 2019; Ahmad et al. 2015), can also play a part in the healing process (Pereira and Maraschin 2015). The synchronisation of physiological wound healing process with antimicrobial and immunological activity is logical as wounds are complex environment where microorganisms are active stakeholders (Joshi et al. 2013; Patil et al. 2012).

In the same vein, Mulukutla and Kale (2019) reported that autoclaved *M. paradisiaca* leaves were parallel in

performance as dressing for facial abrasion relative to polyethylene surgical drape dressing (PESG).

#### Anticancer activity

Vijayakumar et al. (2017) reported that plantain peel aqueous extract-synthesised gold nanoparticles inhibited in vitro A549 lung cancer cells at a dose between 25 and 100 µg/mL significantly relative to DMSO, saline, peel extract, and H<sub>2</sub>O<sub>2</sub> where peel extract performed better than other controls. IC<sub>50</sub> was estimated at 58 µg/mL with the apoptotic pathway assumed to be responsible for cytotoxic activity. This study provides a scientific justification for the use of *M. paradisiaca* in traditional management of cancer and allied inflammatory conditions (Correa et al. 2016; Krishnan et al. 2014; Pereira and Maraschin 2015).

Apart from lung cancer cell lines, the exudates of plantain pseudostem—which constitute around 31% of the plant mass (Saravanan and Aradhya 2011b)—have been shown to inhibit American Type Culture Collection (ATCC, Rockville, MD) strains of hepatocellular (HepG-2) and human colon (HCT-116) carcinomas (Abdel Ghany et al. 2019). At an IC<sub>50</sub> of 29.4 µL, HepG-2 carcinoma was more sensitive with the highest cytotoxic effect to the cell lines which was observed at a dose of 100 µL.

A related activity to this is the antioxidant effect plantain has. Abdel Ghany et al. (2019) reported that via DPPH scavenging assay, exudate of plantain pseudostem elicited protective activity against free radicals on a concentration-dependent rate with a IC<sub>50</sub> of 2.2 µL. This result suggests that the pseudostem can serve as prooxidant and antioxidant due to the tannins and polyphenols present in the extract. Padam et al. (2012), Karuppiah and Mustaffa (2013), Saravanan and Aradhya (2011a), and Saravanan and Aradhya (2011b) corroborate this result. Specifically, galocatechin, dopamine in peels (Vijayakumar et al. 2017); (+)-catechin, gentisic acid, cinnamic, protocatechuic, ferulic, and caffeic acids (in pseudostem) (Saravanan and Aradhya 2011b); gallic, syringic, *p*-coumaric, and ferulic acids, and catechol (in inflorescence) (Arun et al. 2018) which are antioxidants, have been reported in *M. paradisiaca*. Apart from their ability to mitigate conditions resulting from reactive oxygen species, antioxidant effects are known to reduce the risk of cardiovascular and degenerative diseases and cancer (Saravanan and Aradhya 2011b). This provides a preliminary justification to search for bioactive agents in *M. paradisiaca*.

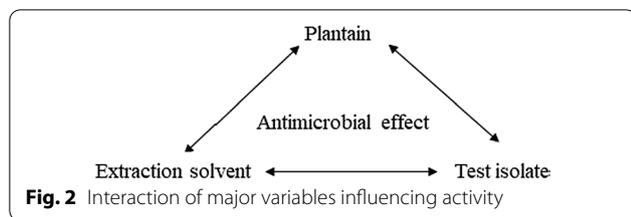
Apart from extracts, the essential oils derived from the fruit have been shown to possess antioxidant properties also. Fahim et al. (2019) reported that the essential oil obtained from the fruit contained  $\alpha$ -thujene,  $\alpha$ -pinene, sabinene,  $\beta$ -myrcene,  $\alpha$ -terpinene,

DL-limonene, tetradecanoic acid,  $\alpha$ -copaene, caryophyllene,  $\beta$ -bisabolene, isocaryophyllene,  $\beta$ -pinene, 1,2-benzenedicarboxylic acid, hexadecanoic acid, 1-nonadecene, 6,9,12-octadecatrienoic acid which possess antioxidant, cytotoxic, and antitumour activity. This suggests that drugs and bioactive prospecting should not be restricted to only extracts or nanoparticles, and other fractions including essential oils can also be veritable sources.

A robust antioxidant effect from *M. paradisiaca* bract aqueous extract-mediated silver nanoparticles has also been reported (Maruthai et al. 2018). This implies that apart from serving as a pharmacologically active agent, it can similarly serve as a scaffold upon which other agents can be developed.

In a comparative study, Oyeyinka and Afolayan (2020) evaluated the antioxidant activity of aqueous, ethanol, and acetone extracts of plantain peel, boiled peel, and flesh. Via DPPH (2,2-diphenyl-1-picryl-hydrazyl-hydrate) assay, the boiled peel extract yielded the most antioxidant effect with the trend being: flesh aqueous extract < flesh acetone extract < peel ethanol extract < peel acetone extract < peel aqueous extract < boiled peel extract at a dose of 0.01 mg/mL. A different trend, using the ferric reducing ability of plasma (FRAP) assay, being peel acetone extract < flesh aqueous extract < flesh acetone extract < boiled peel extract < flesh ethanol extract < peel aqueous extract < peel ethanol extract at the same dose (0.01 mg/mL) was observed. The 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) radical scavenging assay yielded the order flesh aqueous extract < flesh ethanol extract < flesh acetone extract < peel acetone extract < peel ethanol < peel aqueous extract < boiled peel extract, while the inhibitory activity yielded the same pattern except that flesh acetone extract < flesh ethanol extract. This result suggests that care should be taken when comparing the antioxidant activities evaluated using different techniques as they may yield different results and context will be necessary for comparison. For ABTS inhibition assay, the peak concentration of 0.08 mg/mL with acetone extract, among other extracts, yielded the most activity, while the peel, among other parts, yielded the most activity. Significantly, this result suggests that, at some concentrations, aqueous and acetone extracts can cause prooxidant effects to generate free radicals and/or inhibit antioxidant activity. This means that care should be taken in selection of concentrations and choice of solvent during indigenous management of diseases involving plantain.

Antioxidant activity is not restricted to only the ripe fruit as Shodehinde and Oboh (2013) report that aqueous extracts of raw, boiled, roasted, and elastic paste derived from green, unripe plantain and further processed into flours exhibited antioxidant effects in vitro



on the pancreas of rats and in plasma (Shodehinde et al. 2015). This suggests that these pretreatment methods do not eliminate the antioxidant capability of the unripe fruit; thus, the antioxidant contents may be regarded as stable and resilient. This stand appears to be validated by Sasipriya et al. (2014), even suggesting that the treatments enhanced phenolics and tannins content by up to threefold and fivefold, respectively. While this is true, Ibukun et al. (2012) report that ripening has a degrading effect on the polyphenolic content of plantain pulp and its antioxidant activity on hepatic and cerebral tissues of male murine models though Tsamo et al. (2014) posit that upon stage 5 ripening, an increase in phenolic content precedes this reduction. The unripe pulp extracts are regarded as possessing better antidiabetic effect over overripe and ripe pulp extract (Bhingé et al. 2019).

Arun et al. (2018) reported on an *in vitro* cytotoxic activity of inflorescence of plantain, which relative to other parts is less studied, against the HT29 human colon cancer—the third most common cancer across world. The methanolic extract was reported to cause cell cycle arrest and initiation of both intrinsic and extrinsic apoptotic pathways. At a dose dependent rate, effect was amplified. An estimated  $IC_{50}$  of 259.84  $\mu\text{g/mL}$  and 130.26  $\mu\text{g/mL}$ , respectively, for ethyl acetate and methanolic extract via the MTT assay and 268.62  $\mu\text{g/mL}$  and 195.31  $\mu\text{g/mL}$  via the LDH release assay was reported. The methanolic extract, on this metrics, had better anticancer activity which was presumably attributed to the polyphenolic contents. After 24 h, DNA damage and apoptotic changes in HT29 were observed by cell cycle arrest at phase G2/M, a process mediated by cyclin proteins. The authors suggest that apart from polyphenols, they may be other bioactive compounds that induce and regulate the expression of cyclin proteins to effect cell arrest. Disintegration of mitochondrial membrane and loss of cytochrome c and an ultimate reduction in energy generation were similarly observed just as BCL2 anti-apoptotic protein expression was reduced with the converse true for pro-apoptotic BAX while cleaving PARP and caspase 3. It was concluded that these concerted activity leads to apoptosis. The expression pattern of other proteins such as GRP78, calreticulin, CSN, PDH complex, POLR2C, PRDX6, SLC25A35, and X-linked inhibitor of apoptosis, however, in this study, in the context of other reports,

was unsettled, suggesting the necessity of further study to conclusively tie their expression pattern to specifics. Extracts of the inflorescence have also been reported to possess cytotoxic effect on cervical cancer cells in a pathway that implicates caspase-9 (Nadumane and Timsina 2014) and malignant melanoma (Sundaram et al. 2018). Human oral squamous cell carcinoma (OSCC) cell lines (HSC-4) are another carcinoma susceptible to plantain extract (Abd Ghafar et al. 2019). The supernatants obtained from a co-fermentation by *Lactobacillus casei* and *Bifidobacterium bifidum* of soluble dietary fibres—known to aid prevention of physiological diseases such as irritable colon, constipation, diverticulosis, diabetes, cardiovascular diseases, and colon cancer (Pathak et al. 2016)—in the inflorescence and further enriched with short-chain fatty acids possess cytotoxic effect on colorectal cancer cells (HT29) by triggering apoptotic pathways (Arun et al. 2019). Consequently, beyond extracts, fermented products of plantain may, in addition to being nutritional sources, be a nutraceutical source of bioactive antitumour agents.

Harsha Raj et al. (2017) report that ethyl acetate extract of plantain roots, in *in vitro* and *in vivo* assays, demonstrated pro-apoptotic and anti-angiogenic activity against the severely metastatic and aggressive dual invasive ductal breast cancer cell lines (MCF-7 and MDA-MB-231) and human umbilical vein endothelial cells (HUVEC). Via a MTT assay, an  $IC_{50}$  of 60  $\mu\text{g/mL}$ , significantly lower than that reported by Arun et al. (2018) at 259.84  $\mu\text{g/mL}$  with 20  $\mu\text{g/mL}$  yielding a DNA synthesis decrease of 61.6% for HUVEC, 71% for MCF-7, and 75% in for MDA-MB-231 demonstrating its cytotoxic effect by suppressing angiogenesis by 76%. In the murine models, a reduction of 50% suggests anticancer effect. This result is significant in that it adds anti-angiogenic activity to one of the mechanisms that plantain extracts mediate anticancer activity via rigorous data validation by several *in vitro* and *in vivo* assays. The cytotoxic effect of (methanolic) extracts of plantain roots has similarly been corroborated via the brine shrimp lethality test (Chowdhury et al. 2016).

#### Antidiabetic activity

The use of plantain in indigenous management of diabetes with a high global burden (Meigs 2019), more so in Africa (Tekola-Ayele et al. 2013) where health institutions reel under several strains, necessitates the investigation of the scientific justification.

Aqueous extracts and methanolic fractions of *M. paradisiaca* flowers and bract produced antidiabetic effect in male Wistar rats experimentally induced diabetes using intravenous streptozotocin (STZ). Of the lot, methanolic fractions of the flower yielded the best glucose

tolerance effect, after treatment for 15 days, with aqueous extract of the bract following closely comparable to insulin treatment. All the extracts and fractions, however, had improvement relative to the untreated control group due to the presence of flavonol glycoside and anthocyanins in the fractions and extracts which have severally been shown to possess anti-hyperglycaemic activity (Vilhena et al. 2020). The authors recommend the aqueous bract extract over methanolic fraction due to the ease of obtaining aqueous extracts over methanolic fractions. Jawla et al. (2012) corroborate the antidiabetic effect of flower extract within a week. Arun et al. (2017) validate the antidiabetic activity of methanolic flower extract attributable to the polyphenolic compound and dietary fibres present, thus backing calls for the exploration of inflorescence as a potential functional food and/or nutraceutical (Lau et al. 2020) with excellent nutritional and organoleptic properties (Adelekan et al. 2019).

Other than extracts and fractions, Shodehinde et al. (2015) report that unripe pulp of *M. paradisiaca* reduced blood glucose levels by inhibiting intestinal  $\alpha$ -glucosidase, pancreatic  $\alpha$ -amylase, and angiotensin-I-converting enzyme (ACE) in experimentally diabetic adult male Wistar rats after 14 days of oral administration due to the polyphenolic content. Syringin (50 mg/kg body weight) isolated from the ethanolic extract of plantain flower reversed diabetic indices in experimentally diabetic rats, upon oral administration with no observable acute toxicity after 30 days. It is hypothesised that syringin, a phenyl-propanoid glucoside with the chemical formula 4-[(1E)-3-hydroxyprop-1-en-1-yl]-2,6-dimethoxyphenyl-D-glucopyranoside, acts by maintenance of glucose homeostasis and C-peptide levels (Krishnan et al. 2014). It has also been suggested that anti-hyperglycaemic activity may also be mediated by the down-regulation of the inflammatory cytokines TNF- $\alpha$  and IL-1 $\beta$  while up-regulating the titres of transforming growth factor- $\alpha$  (TGF- $\alpha$ ) in Inbred Charles-Foster albino rats induced with STZ-induced diabetes administered (orally) with 100 mg/kg of the ethanolic extract of unripe fruit (Kumar et al. 2013). These hypotheses have been reiterated by Abdel Aziz et al. (2020) though activity was attributed to phytol, stigmasterol,  $\beta$ -sitosterol, and vitamin E.

Via a diet-based therapy, Famakin et al. (2016) report that plantain-based dough meals—supplemented with cassava fibre and soybean cake—resulted in lower blood glucose, implying that a plantain-based diet, in addition to chemotherapy, can successfully manage the condition though the concern about interaction will need to be addressed. The rich content of the micronutrients potassium and sodium in plantain has also been suggested as responsible for this effect due to their fundamental role in metabolism, bodily fluids and structural

tissues composition. Results from Ajiboye et al. (2018) and Oluwajuyitan and Ijarotimi (2019) support the use of plantain-based diet in the management of diabetic and related dyslipidemic conditions.

Other reports have supported the claimed antidiabetic effect of plantain (Eleazu et al. 2013, 2016), its extracts (Kappel et al. 2013; Navghare and Dhawale 2017; Reddy and Hemachandran 2014; Shanmuga and Subramanian 2012), and nanoparticles (Anbazhagan et al. 2017) using different parts (Vilhena et al. 2018; Parmar and Kar 2008).

#### Antiulcer activity

In other medicinal effects explained earlier, it has been shown that plantain has, in addition to these activities, a corresponding antiulcer in models with co-infection. Diabetes is known to be associated with gastric ulcer (Boehme et al. 2007); thus, Kumar et al. (2013) reported that methanolic extract of plantain pulp elicited antiulcerative effects in diabetic rats. Oral administration of 100 mg/kg resulted in remediated ulcer area by increasing the titre of TGF- $\alpha$ , suggesting that activity is related to promoting TGF expression due to the flavonoid content which is supported by others (Alese et al. 2017; Loganayaki et al. 2010; Yakubu et al. 2015). The upregulation is tempered by a yet unknown process, implying that further studies ought to modify the formulation to eliminate this diminishing effect. Vadivelan et al. (2006) suggest that micronutrients and minerals play a role in the attenuation of ulcer index, improved mucus barrier, and regulation of non-protein sulfhydryl group. This mechanism along with thickening of mucosal epithelium and collagen deposition has been substantiated by others (Alese et al. 2018). Apart from flavonoids, syringin, a phenylpropanoid glucoside isolated from *M. paradisiaca* flower, is reported to be active in ulcer treatment (Krishnan et al., 2014).

The antiulcer activity of plantain does not appear to be related to the inhibition of *Helicobacter pylori* which is implicated in gastric ulcer (Goel et al. 2001; Kumar et al. 2013). On the other hand, ethanolic extract of the pseudostem, at a dose-dependent scale, decreased the acidity of gastric juice without an effect on secreted volume (Khamboonruang et al. 2015). The same has been said of the methanolic extract of unripe *M. paradisiaca* as well as interacting with epidermal growth factor receptor (EGFR) and mediating an elevated expression of PECAM-1, a protein angiogenesis and cell adhesion (Alese et al. 2017) pointing to the possibility of an angiogenetic pathway in gastric ulcer healing in murine models.

Table 2 summarises some reported traditional and medicinal properties.

**Table 2** Comparative analyses of traditional and medicinal applications of plantain parts

Application	Part used	Extraction method	Dose (mg/kg)	Effects/findings	References
Antidiarrhoeal	Pulp	Flaked	–	Reduces/stops diarrhoea; thus an effective antidiarrhoeal agent	Rabbani et al. (2001), Debaandya and Namrata (2010)
Antidiabetic	Pulp	Ethanollic	100–800	Reduces blood glucose concentration; has antidiabetic effect	Singh et al. (2007)
Antiulcer	Pulp	Ethanollic, aqueous; methanollic	500	Decreases gastric juice; effective against ulcer	Goel et al. (2001), Pannangpetch et al. (2001)
Antioxidant	Pulp	Methanollic	–	Reverses increased lipid peroxidation; a good antioxidant	Goel et al. (2001)
Cholesterol lowering	Pulp, peel; root	Freeze-dried, dried; methanollic	100–500	Corrects histopathological/biochemical imbalances; a good cholesterol normalising agent	Mallick et al. (2006), Parmar and Kar (2008), Vijayakumar et al. (2008)
Liver/kidney protection	Pulp, peel, root; stem	Ethanollic; aqueous	200–500	Reversed and normalise liver and kidney functions; ability to protect liver and kidney	Iweala et al. (2011), Nirmala et al. (2012), Oyewole et al. (2015)
Hair growth and skin protection	Pulp; stem	Aqueous	–	Promotes healthy skin and hair; protects skin and hair	Rojas et al. (2006), Savali et al. (2011), Kumar et al. (2012)
Blood clotting and wound healing	Pulp; stem	Methanollic; aqueous	–	Reduces bleeding & clotting times; possesses haemostatic and wound healing properties	Agarwal et al. (2009), Novak et al. (2003), Weremfo et al. (2011)
Antihypertensive	Pulp	Dried	–	Lowers mean arterial blood pressure to normal; capable of normalising blood pressure	Osim and Ibu (1991)

**Table 3** Phytochemical composition of plantain

Phytochemicals	Values (mg/100 g)			References
	Peel	Leaf	Flower	
Tannins	28.4	115	88.31	Adeolu and Enesi (2013), Akinsanmi et al. (2015)
Saponin	327	563.33	1430	Adeolu and Enesi (2013), Akinsanmi et al. (2015)
Phenols	89.4	4.5	5.83	Adeolu and Enesi (2013), Akinsanmi et al. (2015)
Flavonoids	1.0	145	3.98	Adeolu and Enesi (2013), Akinsanmi et al. (2015)
Alkaloids	–	24	156	Adeolu and Enesi (2013)

### Effect of extraction technique and solvent on extract

The technique of extraction (Correa et al. 2016; Do et al. 2014; González-Montelongo et al. 2010; Monteiro et al. 2020; Pietrzak et al. 2014; Waszkowiak et al. 2015) and solvents (Correa et al. 2016; Do et al. 2014; Monteiro et al. 2020) has impact on the phytochemical constituents obtained from *M. paradisiaca* and consequently its bioactive activity (Correa et al. 2016;

González-Montelongo et al. 2010). The pharmacological action of plantain is mostly attributed to the phenolic content which polar solvents are best suited for extracting (Do et al. 2014; Monteiro et al. 2020). This may explain why most studies utilised polar solvents. Of the lot, methanollic extracts appear to be the most active.

Heat, also, appears to be a critical factor. González-Montelongo et al. (2010) report that elevated

**Table 4** Nutritional compositions of plantain

Phytochemicals	Values (mg/100 g)			References
	Peel	Leaf	Pulp	
Sodium	162	280	2.0	Adeolu and Enesi (2013), Akinsanmi et al. (2015), United States Department of Agriculture (2018)
Potassium	235	40	431	Adeolu and Enesi (2013), Akinsanmi et al. (2015), USDA (2018)
Calcium	100	135	2.0	Adeolu and Enesi (2013), Akinsanmi et al. (2015), USDA (2018)
Magnesium	76	18	41	Adeolu and Enesi (2013), Akinsanmi et al. (2015), USDA (2018)
Iron	5.6	14	0.75	Adeolu and Enesi (2013), Akinsanmi et al. (2015), USDA (2018)
Phosphorus	360	151.67	31	Adeolu and Enesi (2013), Akinsanmi et al. (2015), USDA (2018)
Zinc	–	–	0.18	USDA (2018)
Vit. C	11.72	8.17	20.2	Adeolu and Enesi (2013), Akinsanmi et al. (2015), USDA (2018)
Vit. A	–	0.97	–	Adeolu and Enesi (2013)
Thiamine	–	0.20	0.10	Adeolu and Enesi (2013), USDA (2018)
Riboflavin	–	0.50	0.10	Adeolu and Enesi (2013), USDA (2018)
Niacin	–	1.13	0.55	Adeolu and Enesi (2013), USDA (2018)
Vit. B6	–	–	0.07	USDA (2018)
Protein	11.47*	–	1.25*	Adeolu and Enesi (2013), USDA (2018)
Fibre	8.47*	–	2.2*	Adeolu and Enesi (2013), USDA (2018)
Carbohydrate	60.87*	–	36.66*	Adeolu and Enesi (2013), USDA (2018)

Values with asterisk (\*) are in grams (g)

temperature improved extraction efficiency and solubility of phytochemical constituents but can cause degradation of volatile constituents just as Correa et al. (2016) asserts that with supercritical CO<sub>2</sub> extraction yield is lowered with the converse true for propane. This seems to suggest that there is a complex association between temperature and solvent that require elucidation.

The wide range of extraction technique reported and the variations makes comparison difficult since this influences phytochemical content and eventually its activity. This leads us to call for a standardisation of extraction protocol (to serve as baseline) that can be compared with other optimised protocols.

A list of some of the phytochemical and nutrient components of *M. paradisiaca* is presented in Tables 3 and 4, respectively.

## Conclusions

Different parts of *M. paradisiaca* have been studied extensively and found to modulate physiological activities and antimicrobial effects on various microorganisms. However, as against most of the conventional antimicrobials used in pharmacological and cosmetics preparations, the mechanisms of actions of this potent antimicrobial and medically active plant on each of the applications have not been well studied. Similarly, while antimicrobial—generally—studies are extensive, limited antiviral and in vivo reports exist. Putatively,

the bioactive metabolites that appear to mediate antimicrobial activity are stigmasterol and  $\beta$ -sitosterol (phytosterols) and the triterpenes trio of 31-norcycloclaudenone, 24-methylene-cycloartanol, and cycloeucaenone. The paucity of in vivo and antiviral studies are gaps that require to be earnestly. As for physiological conditions, extensive and rigorous studies around which begs the question of why a formal drug development scheme from *M. paradisiaca* has not been pursued by pharmas in this regard.

Isolation, purification, and characterisation of the active ingredients, apart from syringin, from *M. paradisiaca* are also necessitated to potentiate its exploitation. Finally, while there is paucity of data in toxicity studies where there are, they have been deemed to be highly tolerated and safe.

## Abbreviations

ABTS: 2,2'-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); ACE: Angiotensin-I-converting enzyme; DNA: Deoxyribonucleic acid; DPPH: 2,2-Diphenyl-1-picryl-hydrazyl-hydrate; EC<sub>50</sub>: Effective concentration; EGFR: Epidermal growth factor receptor; FRAP: Ferric reducing ability of plasma; HAuCl<sub>4</sub>: Chloroauric acid; HAV: Hepatitis A virus; HSV: Herpes simplex virus; HUVEC: Human umbilical vein endothelial cells; IC<sub>50</sub>: Inhibitory concentration; MIC: Minimum inhibitory concentration; NK: Natural killer; OSCC: Oral squamous cell carcinoma; STZ: Streptozotocin; WHO: World Health Organisation.

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**Authors' contributions**

AKA, ASA, TOA, FRZ, NRA, and AS reviewed studies on antimicrobial activities. OJO reviewed antidiabetic studies and mineral content. ASA wrote the initial draft. TOA reviewed the initial draft; description, distribution, and traditional uses; antimicrobial activities and other medicinal properties and wrote the manuscript to make the current structure. All authors read and approved the final manuscript.

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**Competing interests**

The authors declare that they have no competing interests.

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