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ANTIBACTERIAL ACTIVITY OF *Aloe vera* GEL AND ETHANOLIC EXTRACTS ON SOME BACTERIAL INFECTIOUS AGENTS OF CLINICAL ORIGIN

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Abstract

The study examined the antibacterial activity of *Aloe vera* gel and ethanolic extract against some infectious bacterial agents (*Escherichia coli, Pseudomonas aeruginosa, and Staphylococcus aureus*) of clinical origin. This in a bid to further exploit herbal plants for innovative drugs towards relieving the threat of microbial antibiotic resistance and advancing in herbal medicine. The ethanolic extract obtained by ethanol extraction and the Aloe gel removed from the fleshy stem of Aloe plant were applied for the preparation of various standards, and subsequent impregnation onto sterile circular disc. Afterwards, the pure cultures obtained from microbiological screening of bacterial isolates were tested for antimicrobial susceptibility test by disc diffusion method. The findings revealed *P. aeruginosa* and *E. coli* portrays significant susceptibility to the gel and ethanolic extract of *Aloe vera* across all the standards in a dose-dependent pattern. However, the Aloe gel depicted higher antibacterial efficacy than the ethanolic extract due to certain reasonable factors. The antibacterial activity of these Aloe extracts was attributed to the combined presence and actions of the assorted bioactive, nutritional and phytochemicals of the Aloe plant. On the contrary, *S. aureus* showed complete resistance to both Aloe extracts with no zones of inhibitions recorded even after prolonged incubation. This suggested *S. aureus* as a resistant strain admissibly owing to the clinical origin of these isolates. This study further established *Aloe vera* as herbal antibacterial agent that could be exhaustively tapped for pharmaceutical productions specifically new line of potent drugs to compliment the orthodox medicine.

INTRODUCTION

The exploitation of herbal plants and plant products for the treatment of microbial infections is now gaining a global stand due to the quest for new potent antimicrobial drugs to combat the threat of microbial antibiotic resistance. It is well acknowledged that antibiotic therapy in contemporary medicine are often faced with common challenge of increasing emergence of microbial resistance (multidrug resistance) to antimicrobial drugs. This has exacerbated many clinical infections, consequently making the future management and therapy of infectious diseases difficult [1]. In a pursuit for recourse, scientists now seek to look inwards and dig deeper into herbal alternatives for therapy of microbial infections. Herbal medicinal plants are naturally occurring, plant-derived materials with negligible or no industrial modification used for disease treatment in local practices [2]. DaSilva et al. [3] related that the application of herbs for the treatment of disease is virtually universal in non-industrialized societies - this implies that the herbal

medicines are widely known custom in advancing countries with a historic tradition in the practise of medicinal plants, and in some advanced countries with fitting policies for registration of plant medicines [4].

Medicinal plants are known to be rich in varieties of secondary metabolites like the alkaloids, tannins, terpenoids, flavonoids, quinones, phenols and many others, as such has been used worldwide to treat several diseases and infection mostly in the traditional medicine setup [5]. These medicinal herbs and plants can be grown from seeds collected from parts of larger trees or from unwanted weeds in nature. Besides, some serves as spices which yields useful medicinal compounds for food seasoning [2].

Many studies of traditional medicine relevance have evidenced that herbal plants and its extract possess multi-antimicrobial constituents and may fairly justify why many conventional drugs originated from plant sources [6]. Several medicinal plants with pharmaceutical properties have been deciphered however, *Aloe vera* is virtually the most used medicinal plant globally [7]. Also, labeled as one of the most famous medicinal plants found in many geographical regions known as a succulent plant species, widely speculated to be effective against wide range of diseases and ailment due to its medicinal properties [8, 9]. Historically, its first reference was in English and translated by John Goodyew in A.D. 1655 (of Dioscorides' Medical treatise De Materia Medica) [10], and it became a notably recognised medicinal plant with various healing properties among several cultures of the Egyptians, Roman, Greek, Arab, Indian, Mexicans, Japanese and Chinese [11, 12]. Among its earliest medicinal usage dated back to the mid-1930 when it was fruitfully applied for the treatment of chronic and severe radiation dermatitis [10]; and in 2100 B.C. where it was stated in an assembly of Sumerian clay tablets [7]. These historical uses of *Aloe vera* relevantly serves as major pointer for its cultivation in later years and first grown in 1920 for pharmaceutical supply [13]. Now, *Aloe vera* plant extract are extensively used in the cosmetics, pharmaceuticals and different medicine industries, being markedly as variously having reviving healing, or relaxing properties [14].

Tyler et al. [15] stated that the word 'Aloe' was derived from an Arabic word 'alloeh' which signifies shining and bitter (mostly associated to the peripheral bundle sheath cells that result to a bitter taste and yellow exudate); while ''vera'' in Latin means ''True'' [12]. Taxonomically, *Aloe vera* is classified as a plant (in plant kingdom), which belong to the class *Liliopsida* (Monocotyledons), order *Liliales*, family of *Aloeaceae*, genus of *Aloe L.* and species of *Aloe barbadensis Mill* or *Aloe vera* [7]. Thus, the scientific name for *Aloe vera* plant is *Aloe barbadensis Mill.* Synonymous to *Aloe vera (L.) Burm. F.* in accordance with the International Rules of Botanical Nomenclature [16]. Though, *Aloe vera* is also called by other names among which are *Aloe chinensis Bak, Aloe elongate Murray, Aloe indica Royale, Aloe officinalis Forsk, Aloe perfoliata, Aloe rubescens DC, Aloe vulgaris Lam* and others [17]. However, over 350 species of Aloe plant exist though *Aloe barbadensis Mill.* and *Aloe arborescens* are often the predominant species [18]. In description, the Aloe plant is a shrubby (arborescent), perennial, xerophytic, succulent and pea-green colored plant which grows mostly in the dry regions of Africa, Asia, Europe, America and some parts of India [12]. It has yellow flowers; the leaves are triangular and spear-like with thorny ridges and arranged in a rosette configuration. Also, appears meaty when filled with gel that arises from the transparent central mucilaginous pulp [19].

This study on the antibacterial properties and activity of *Aloe vera* plant is paramount to decipher and exploit its current medicinal value; this is now long overdue owing to its substantial historical therapeutic usage in traditional herbal medicine and inclusion in the modern medicine for the industrial production of clinical products. Therefore, this research was targeted at examining the antibacterial activity of *Aloe vera* gel and ethanolic extracts against infectious bacterial agents of clinical origin.

MATERIALS AND METHODS

Materials

Some of the materials used for this study include the *Aloe vera* plant, filter paper, paper puncher, distilled water, Gram staining reagents, Kovac's reagent, Hydrogen peroxide, 1% Sulfuric acid, 1.175% barium chloride, and blood serum.

Clinical Bacteria Isolates

Bacterial isolates of clinical origin used in this study include *Escherichia coli, Staphylococcus aureus* and *Pseudomonas aeruginosa.* These isolates were collected from microbiology laboratory of Federal Teaching Hospital (FTH) Gombe and were subjected to microbiological analyses to identify and confirm the isolates. Bacterial isolates of clinical origin are mostly isolated from clinical samples (such as urine, faeces, sputum, blood and other body fluids) requiring clinical examination.

Collection and Preparation of *Aloe vera* Plant

Fresh *Aloe vera* plant was collected from the garden of Biological Sciences department of Gombe State University and was duly identified by a botanist in the department. The *Aloe vera* plant collected was properly washed with distilled water to remove any dirt harboured by the plant. The *Aloe vera* plant intended for ethanolic extraction was aseptically dried and grinded to powdery form in preparation for the extraction procedure in the laboratory.

Ethanolic and Gel Extraction of *Aloe vera*

Extraction using *Aloe vera* was performed as described by Fatope and Hamisu [20] and Parekh et al. [21]. 20 grams of the *Aloe vera* powder was weighed and soaked in 200 mL of ethanol in conical flasks for two weeks at room temperature with regular shaking. The resulting *Aloe vera*-ethanol mixture was then filtered, and solvent evaporated to concentrate the extract afterwards preserved at 4 °C prior to sensitivity testing assay.

The *Aloe vera* gel is an exudate produced by the thin-walled tubular cells in the inner central zone of the leaf termed parenchyma. This jelly substance is a clear, transparent, tasteless and odourless slippery mucilage or gel [11, 22]. The *Aloe vera* gel was obtained by cutting open the fresh fleshy stem of the *Aloe vera* plant using a sterile knife and carefully collecting the content gel into a sterile beaker. The gel collected was further blended to obtain a gel stock homogenate and stored at 4 °C prior to sensitivity testing.

Sub-culturing and Purification of Bacteria Isolates

Stock cultures of *E. coli, S. aureus* and *P. aeruginosa* were collected from microbiology laboratory of the FTH Gombe and sub-cultured on nutrient agar. Colonies from fresh cultures of these test organisms obtained from an overnight sub-cultured plate were picked with sterile inoculating loop then streak-plated on nutrient agar to obtain pure cultures. Distinct colonies were picked from the pure culture plates for identification and biochemical confirmation of the isolates. The pure colonies were further sub-cultured on agar slants to obtain a stock culture of the pure bacteria isolates.

Microbiological Identification and Confirmation of Bacteria Isolates

After sub-culturing and isolation of pure cultures from the clinical isolates collected from FTH Gombe based on standard microbiological protocol, the colonies from the pure culture were subjected to Gram staining, microscopy and various biochemical analyses for proper identification and confirmation of these Isolates.

Gram Staining

This was employed for the identification of Gram-positive and Gram-negative microbes. A smear of the bacterial isolate was prepared on a clean grease-free slide then slightly heat-fixed before staining with gram staining reagents. Their gram reaction and cell morphology were observed under the microscope at x100 objective lens [23].

Biochemical test

Confirmatory biochemical tests that includes Catalase, Coagulase, Indole, Citrate Utilization, Motility, Urease, and Kligler's Iron Agar test were carried out for further cogent confirmation of the bacterial isolates. Protocol for biochemical analyses described by Cheesbourgh [23] was applied here.

Standardization of Inoculum

The identified and confirmed pure bacteria isolates from an overnight plate was emulsified into peptone water contained in a test tube using a sterile wire loop then incubated for 24 h at 37 ºC. From the overnight culture tube, 1 mL was dispensed into a sterile test tube, diluted with distilled water by direct dilution then compared with 0.5 McFarland's standard [23].

Preparation of Stock and Standard Concentrations of *Aloe vera* Extract

The crude and undiluted ethanolic extract of *Aloe vera* and the gel supposed 100 % (v/v) was used as the stock concentrations, while several standard concentrations of 20, 40, 60 and 80 % (v/v) were prepared from the stock by appropriate and proportionate dilution with distilled water. The stock and the prepared standard concentrations of both ethanolic and gel extracts were used for the sensitivity testing.

Sensitivity Disc Preparation and Antibacterial Susceptibility Testing

Paper discs of 6 mm diameter were punched from Whitman's No. 1 filter paper using a paper puncher. Batches of discs were placed into Bijou bottles and sterilized by autoclaving at 121 ºC for 15 minutes. The sterilised discs were impregnated with the stock and prepared standard concentrations (100, 80, 60, 40, 20 % (v/v)) of the ethanolic extract of *Aloe vera* by separately dispensing the prepared concentrations into the bijou bottles containing the sterilized discs. This approach was applied for the preparation discs containing 100, 80, 60, 40, 20 % (v/v) concentration *Aloe vera* gel extract. However, a negative control disc was impregnated with distilled water.

Antibacterial susceptibility testing was achieved using agar disc diffusion technique described by NCCLS [24]. Sterile swab sticks were used to swab the standardized inocula onto the surface of Mueller Hinton agar. Afterwards, sterile forcep was used to carefully place the sensitivity discs impregnated with different concentrations of ethanolic and gel extracts of *Aloe vera* in strategic positions on the surface of the Mueller Hinton agar plates. Inoculated plates were inverted and incubated for 24 h at 37 °C, then diameter zones of inhibition in each plate was measured using a meter rule at the end of the incubation [24].

RESULTS AND DISCUSSION

The antibacterial activity of gel and ethanolic extract of *Aloe vera* on some bacterial isolates (*P. aeruginosa, E. coli and S. aureus*) of clinical origin was studied. This is relevant to substantiate the antimicrobial potency of *Aloe vera* for potential exploitation in modern-day herbal medicine. The results for biochemical analysis, gram staining reaction and morphological identification of the bacterial isolates (*E. coli, P. aeruginosa, and S. aureus*) used in this study is shown in Table 1 below. This table confirmed the identity of the clinical test bacterial isolates used for this study.

Table 1. Microscopic morphology and biochemical properties of test organisms.

Organisms	GR	Morp.	Ur	Cat	Co	Cit	Mot	Ind	MR	Ox	KIA			
											Gas	H_2S	Slope	Butt
E. coli	-	srs	-	+	-	-	+	+	+	-	+	-	Y	Y
P. aeruginosa	-	srs	-	+	-	+	+	-	-	+	+	-	R	Y
S. aureus	+	cc	-	+	+	-	-	-	+	-	-	-	Y	Y

Key: Positive sign (+) signifies positive reaction, Negative sign (-) signifies negative reaction, Ur = urease test, Cat = catalase, Co = coagulase test, Cit = citrate test, Mot = motility test, Ind = indole test, MR = Methyl red test, Ox = Oxidase test, KIA = Kligler Iron Agar, Morp: microscopic morphology and Cc = cocci in cluster, srs = short rods in singles.

Susceptibility of Bacterial strains to *Aloe vera* extracts and antimicrobial properties

The results of the antibacterial susceptibility/resistance of *P. aeruginosa, E. coli and S. aureus* tested against various concentrations of gel and ethanolic extracts of *Aloe vera* is provided in Figure 1, 2 and table 2 respectively. Two bacterial isolates (*P. aeruginosa,* and *E. coli*) portrays significant susceptibility to both the gel and ethanolic extract of *Aloe vera* relative to the negative control (Figure 1 and 2). On the contrary, *S. aureus* was resistant to the stock and standard concentrations of *Aloe vera* gel and ethanolic extract as shown in Table 2.

In Figure 1, the highest zones of inhibition recorded by *Aloe* gel and ethanolic extracts tested against *P. aeruginosa* were 32 mm and 20 mm at 100 % (v/v) respectively, while the lowest inhibition zones recorded were 12.5 mm and 8.0 mm at 20 % (v/v) concentration respectively. For *E. coli,* Figure 2, depict the highest zones of inhibition produced by *Aloe vera* gel and ethanolic as 27.0 mm and 23.0 mm at 100 % (v/v) concentration respectively while the lowest was 15.0 mm and 10.0 mm at 20 % (v/v) respectively. In Table 2, susceptibility test with both *Aloe vera* extracts against *S. aureus* produced no inhibition zones at highest and lowest concentration of gel and ethanolic extract of *Aloe* used. This clearly implies that *S. aureus* conferred resistance to the gel and ethanolic extracts of *Aloe vera*. Its worthy to note that Figure 1 and 2 shows a dose-dependent susceptibility pattern for *Aloe vera* gel and ethanolic extract tested against *P. aeruginosa* and *E. coli*. This implies the increase in the zones of inhibitions produced is proportional to the increase in the doses or concentrations of the Aloe gel and ethanolic extract used for susceptibility testing. This dose-dependent increase in susceptibility displayed agrees with the findings of Mohammed et al. [25].

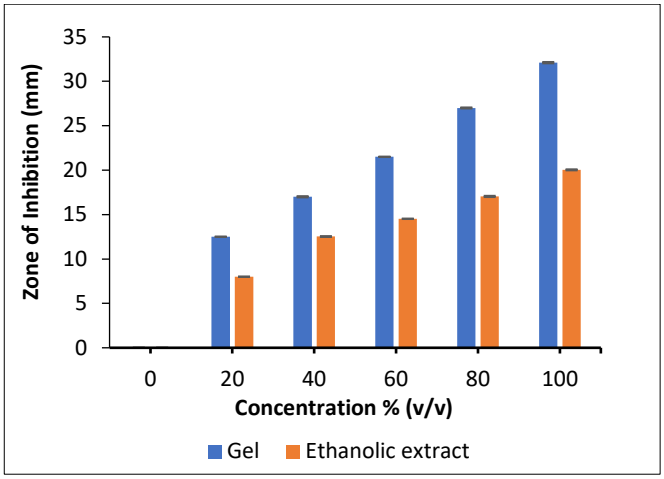

Figure 1. Antibacterial susceptibility of *P. aeruginosa* to various concentrations of gel and ethanolic extracts of *Aloe vera* plant. Results represented in bars are mean of technical replicates (n=3) of zones of inhibition measurement where SE ≤ 0.1 as represented in error bars. Statistical relevance indicates significant differences in mean of values recorded for all standards in relation to the negative control where $P<0.05$.

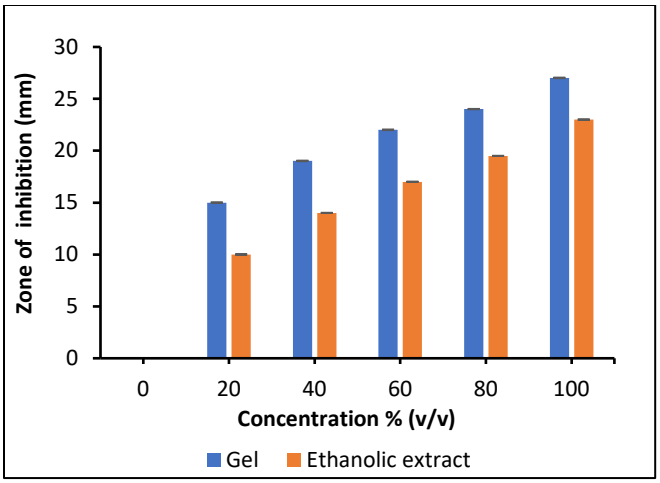

Figure 2. Antibacterial susceptibility of *E. coli* to various concentrations of gel and ethanolic extracts of *Aloe vera* plant. Results represented in bars are mean of technical replicates (n=3) of zones of inhibition measurement where SE < 0.1 as represented in error bars. Statistical relevance indicates significant differences in mean of values recorded for all standards in relation to the negative control where P<0.05.

The result of the susceptibility testing (Figure 1 and 2) convincingly denotes that *P. aeruginosa* and *E. coli* obtained from a clinical setting were susceptible to the gel and ethanolic extract of *Aloe vera* plant thus signifying its antibacterial potency. This is in accordance to the work conducted by Mbajiuka et al. [26] who reported the antimicrobial activity of *Aloe vera* on some human pathogens where it was related that the gel and leaf possess inhibitory effect on *E. coli* and *P. aeruginosa.* Again, this corroborated several studies, among which is an *in vitro* study by Dalia et al. [7] who reported *Aloe vera* exhibited antimicrobial potency on some Gram-negative and Gram-positive bacterial isolates. In fact, other studies (e.g., Ali et al. [27]) also reported its antifungal properties, and antiviral activities [28] which further specifies its broad antimicrobial relevance. Traditionally, *Aloe vera* is often applied in ointments and creams to aid healing of wounds, burns, eczema, psoriasis and internally used as laxative [29, 30]; again, this among many others somewhat highlight the historical application of *Aloe vera* in local herbal medicine.

It should be acknowledged that the screening of the phytochemicals and bioactive components of *Aloe vera* gel and extract was not investigated in this study. However, endless relevant studies have emphasised on the super-rich phyto bioactive and antimicrobial constituents of *Aloe vera* consequently attributing its antimicrobial efficacy to these crucial constituents. For instance, Park and Jo [31] reported that *Aloe vera* leaf have been reported to comprises of more than 75 nutrients and 200 active compounds that includes 18 amino acids, 20 minerals, and 12 vitamins. *Aloe vera* have also been reported to contain various components such as tannins, sterols, organic acids, enzymes, saponins, mono- and polysaccharides, vitamins and minerals [29]. While Bruneton [32] in his findings claimed aloine, an anthraquinone heteroside are the key active constituent of *A. vera* plant extract. Antherton [33] also related that the potentially bioactive constituents of *Aloe vera* include sugars, lignin, saponins, anthraquinones, salicylic acid and amino acids. This shows that aside from its medicinal constituents, *Aloe vera* has been vastly reported to contain nutrients including lipids, polysaccharides, vitamins, fatty acids, proteins, dietary fibre, ash and others [34, 35]. However, many factors such as the species, edaphoclimatic conditions and age of the plant can disrupt the nutrients components of *Aloe vera* plant [7, 35]. Minerals like calcium, chromium, copper, magnesium, selenium, manganese, sodium, potassium, zinc and many others have been found in Aloe plant [12]. Also 16 dissimilar polysaccharides were detected in *Aloe vera* leaf [36].

Crucial studies have claimed *Aloe vera* holds variety of beneficial activities such as antibacterial, anti-inflammatory, antioxidant, anticancer, anti-inflammatory, hepatoprotective, immunomodulatory, antiulcer and antidiabetic properties [36], and this portray reason it is often referred as a ‘‘wonder plant’’ [7]. Previous study by Ronald et al. [19] reported varied high percentage (ranging from 60 to 90%) of the *Aloe vera* extract was bactericidal against infectious microbial agents like *P. aeruginosa, S. faecalis* and most Coliform group. Specifically, relating Aloe’s phyto- and bioactive components to its various general beneficial activities; Ejoba [37] reported that the antimicrobial activity is mainly due to the presence of phytochemicals such as alkaloids, flavonoids, steroids, terpenoids glycosides, carbohydrates and tannins in *Aloe vera* which denotes it medicinal use. Also, saponin which is one of the active components of *Aloe vera* offers antiseptic properties [19]. Dalia et al. [7] demonstrated that *Aloe vera* depict antimicrobial activity on Gram-positive and Gram-negative isolates and attributed polysaccharides to direct bacterial action via phagocytic leucocytes stimulation to kill bacteria. The Aloe plant has anti-allergy and anti-inflammatory properties because of antraquinones which block the regeneration of thromboxane, also inhibit and breakdown bradykinin via bradykinase activity [38] thus, inferred to have several pharmacological properties which include its antibacterial, antifungal, anti-inflammatory and anti-vermin and has immunological properties [39]. *Aloe vera* leaves contain phytochemical such as acetylated mannans, polymannas, anthraquinones C-glycosides, enthrones, other anthraquinones such as emodin and various lectins for possible bioactivity [40]. Another bioactive component of Aloe plant is Acemamman (acetylated gluconmanan), a polysaccharide rich in mannose units is said to improves healing of wounds, modulates immune function and possess antiviral effects while Glucomannan is also a polysaccharide that serves as a good moisturizer thus used in cosmetics [41]. *Aloe vera* is externally used for cicatrisation and internally as laxative because it contains anthraquinone

glycosides [30], also Chun-Hui et al. [42] stated the antioxidant properties of polysaccharides from *Aloe vera.* Besides, other biological activities ascribed to Aloe are antidiabetic, anti-obesity, immune modulator, anti-inflammatory, antioxidant, laxative property and anticancer [7]. Therefore, the antibacterial activity of *Aloe vera* extracts and gel on some clinical bacterial isolates exhibited in this study could be primarily attributed the presence of crucial phytochemicals, antimicrobial ingredients, bioactive and nutritional constituents of the *Aloe vera* plant all put together. Consequently, it is reasonable to state that the biological actions of *Aloe vera* plant extracts are more plausible as a result of synergistic effect of the various combinations of compounds rather than a lone compound [43]. However, it should be acknowledged that the mechanisms of actions of many assorted bioactive components of *Aloe vera* plant is still largely unknown.

Interestingly, the *Aloe* gel showed comparatively higher antibacterial activity than the ethanolic extract against *P. aeruginosa,* and *E. coli* as observed in Figure 1 and 2 while there was an indifference against *S. aureus* due to no susceptibility observed for this study (Table 2). Besides, this higher antibacterial activity portrayed by the *Aloe vera* gel compared with the ethanolic extract was noticed at all concentrations ranging from the stock denoted as the highest concentration (100% (v/v)) to the lowest concentration of 20% (v/v) (Figure 1 and 2). This phenomenon of higher antibacterial activity or efficacy noticed with the *Aloe vera* gel could signify more active components in the Aloe gel than the ethanolic extract leading to increased antibacterial potency. In agreement to this, Davis [10] and Ejoba [37] concluded that the higher effectiveness of the gel is due to the presence of bioactive constituents such as anthraquinones and hormones. Additionally, Ahlawat & Khatkar [17] shows that most of the constituents are found in the gel and not in the leaf and stated that over 200 bioactive chemicals have been detected in *Aloe vera* gel, consequently providing the basis for the gel to be more active than the leaf [10]. Contrary wise, aside from the justification based on the varied number of bioactive and phytochemicals in the Aloe gel and extract, this phenomenon of increased antibacterial efficacy exhibited by *Aloe vera* gel may be expected and judicious as the gel used for susceptibility testing was subjected to no modification after extraction, thus suggesting that all the bioactive components were intact. On the contrary, ethanolic extract may have lost quite significant amount of bioactive and antimicrobial constituents due to the application of heat in its extraction processes. This application of heat could have caused loss of water-soluble components via evaporation and/or irreversible modification rendering the bioactive components useless. Femenia et al. [44] also confirmed the loss of bioactive components in the Aloe extract is due to the processing which may have caused an irreversible modification to carbohydrates, affecting its original structure, and encourage vital changes specifically in the physiological and pharmacological properties of these constituents. Furthermore, Miranda et al. [45] inferred that drying temperature up to 80 and 90 °C exerted an obvious influence on majority of the quality parameter which could significantly lower the physicochemical and nutritional properties of Aloe extract as a result of constituent loss.

Table 2. Results of antimicrobial susceptibility test of Aloe extract against *S. aureus.*

Aloe extracts	Zones of inhibition (mm) for standard concentrations					
	0	20	40	60	80	100 %(v/v)
Gel	0.00	0.00	0.00	0.00	0.00	0.00
Ethanolic extract	0.00	0.00	0.00	0.00	0.00	0.00

Table 2 shows the antibacterial resistance of *S. aureus* to various concentrations of gel and ethanolic extracts of *Aloe vera* plant. Results represent no zone of inhibition recorded for three technical replicates of susceptibility test. Statistical relevance indicates no significant differences in mean of values recorded for all standards relative to the negative control where $P>0.05$.

Resistance of *S. aureus* to *Aloe vera* Extracts

The result of susceptibility testing of the *Aloe vera* gel and ethanolic extract against *S. aureus* in Table 2 shows that *S. aureus* was not susceptible to both the gel and the ethanolic extract of *Aloe vera* but resistant to these Aloe extracts. This is justifiable as it must be reminded that bacterial isolates applied for this study were of clinical origin which implies these infectious microbial agents were isolated from clinical samples (like sputum, blood, urine, stool, swab etc) of patients suffering different ailments such as community-acquired methicillin resistant *S. aureus* (MRSA) infections. To buttress this, David et al. [46] stated that MRSA specific DNA sequences bearing the cassette chromosome *mec* (SCC*mec*) genes or element could be recovered from clinical samples. It is therefore apparent that

the *S. aureus* found resistant to the Aloe gel and ethanolic extract could be an antibiotic resistant strain (e.g., Methicillin-resistant *S. aureus* (MSRA), Vancomycin-resistant *S. aureus* (VRSA) or any other). Unfortunately, the record of the sample source for this strain and the patient antibiotic usage history was not provided to further substantiate this claim, even though it may be safe to hypothesize that this *S. aureus* strain possibly have acquired resistance as a clinical isolate due to prophylactic exposure of the patient to antibacterial drugs such as the methicillin group and β-lactam antibiotics. Alternatively, resistance could be conferred on this strain via resistant gene transfer, mutation and acquisition of exogenous genes [47]. Regrettably, this study did not expand its scope to the detection of multi-drug resistance of these clinical bacterial isolates; besides, it should be acknowledged that no positive control with suitable antibiotic drug was applied for this study - this could have expatiate on the resistance or multi-drug resistance status of these strains specifically the *S. aureus* and pinpoint the class of antibiotics the strain may be resistant to. It's MDR status could further guide on the investigation of the specific resistant genes possessed by the *S. aureus* strain.

Literature have shown that the medicinal application of *Aloe vera* plant are countless and may be under exploited. Currently, the pharmaceutical industries in realization of the valued antimicrobial properties of *Aloe vera* plant are now suitably supplementing pharmaceutical products such as drugs, topical ointments, creams, antiseptics, food, nutritional supplements and others with *Aloe vera* to enhance their antimicrobial benefit.

CONCLUSION

The antibacterial activity of *Aloe vera* plant was studied and it was found that Aloe gel and ethanolic extract possess significantly worthy antibacterial activity against *P. aeruginosa* and *E. coli* but resistant to *S. aureus* of clinical origin. The antibacterial potency of these *Aloe vera* extracts was majorly attributed to the plausible synergistic presence and action of diverse bioactive phytochemicals, nutritional and antimicrobial components as stipulated in several studies rather than single-compound action. However, the mechanisms of actions of these bioactive components of Aloe responsible for therapeutic and antimicrobial influence is still largely unclear. Additionally, it was hypothesized that the *S. aureus* resistant to the Aloe extracts could be a resistant strain as justified by the clinical origin of the strain.

This study proves the use of *Aloe vera* for therapy of different diseases caused by infectious bacterial agents could be effective especially at higher doses thus portrays a huge potential for antimicrobial drugs in modern medicine to combat challenging infections. This potential could be advantageously exploited specifically in pharmaceutical industries to produce new line of drugs in a bid to help combat antimicrobial resistance.

On the other hand, there is need to take this research forward in order to proffer answers to certain crucial research questions thus the following is highly recommended for future studies;

I. *S. aureus* found resistant to the gel and ethanolic extract of *Aloe vera* should be investigated for resistance genes and its MDR status should be verified.

II. New studies on the antimicrobial activities of *Aloe vera* extracts against various known resistant strains of infectious agents should be conducted. This may serve as a frontier for the discovery of new antimicrobial drugs for combating antibiotic resistance.

III. Further study investigating the bioactive and phyto ingredients of the *Aloe vera* gel and ethanolic extract could not be over emphasized. Importantly, the exact mechanisms of action responsible for varied biological activities of Aloe should be principally investigated. This clarification of the modes of action of its biochemical components is paramount for the determination of the most resourceful way of exploiting *Aloe vera* and mapping out its applications in modern medicine.

IV. Extensive investigation on the antifungal activities of *Aloe vera* against pathogenic fungi should be undertaken to increase the data available on the subject.

CONFLICT OF INTEREST

The authors hereby declare no conflict of interests regarding the publication of this manuscript.

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