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(RESEARCH ARTICLE)

COMPARATIVE IN VITRO ANTIBACTERIAL, CIPROFLOXACIN-COMBINATION, AND ANTIOXIDANT ACTIVITIES OF AQUEOUS AND ALCOHOLIC EXTRACTS OF *CYMBOPOGON CITRATUS*

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ABSTRACT

Lemongrass (Cymbopogon citratus) is widely used for traditional medicine and potential antimicrobial and antioxidant properties. This study evaluated the antibacterial activity of aqueous and alcoholic extracts of lemongrass against Staphylococcus aureus and Escherichia coli, the combined effects with ciprofloxacin and free-radical scavenging capacity by DPPH assay. The antibacterial activity was evaluated by the agar disc diffusion method using ciprofloxacin as a positive control and 15% DMSO as a negative control. Antioxidant activity was determined at 10, 20, 40, 80 and 100 mg/mL of extract concentrations with ascorbic acid as the reference antioxidant. The alcoholic extract showed an inhibition zones of 14 mm for S. aureus and 11 mm for E. coli. No antibacterial activity was detected for the aqueous extract. Ciprofloxacin alone showed inhibition zones of 26 and 25 mm against S. aureus and E. coli respectively. The combination of aqueous extract-ciprofloxacin gave zones of 24 and 23 mm while the combination of alcoholic extract-ciprofloxacin gave 25 mm against both organisms indicating no clear synergistic enhancement. In DPPH assay, alcoholic extract showed higher antioxidant activity than aqueous extract with 62.50% radical scavenging activity at 100 mg/mL, while aqueous extract showed 18.75% and ascorbic acid showed 87.50%. To summarize, alcoholic extract showed better antibacterial and antioxidant activities. Further phytochemical characterisation and MIC-, MBC-, checkerboard- and time-kill-based studies are needed to confirm its bioactive constituents and antimicrobial interaction profile. The results suggest that alcoholic extraction is more efficient in recovering active constituents from lemongrass under these conditions.

Keywords: *Cymbopogon Citratus*; Lemongrass; Antibacterial Activity; Antioxidant Activity; DPPH; Ciprofloxacin; Plant Extract.

1 INTRODUCTION

Antimicrobial resistance is now a major global health challenge, threatening our ability to treat common bacterial infections effectively. Based on a systematic analysis of the global burden of bacterial antimicrobial resistance [1], an estimated 1.27 million deaths were directly attributable to resistant infections and nearly 4.95 million deaths were associated with resistant infections in 2019. Among the clinically relevant bacteria, Staphylococcus aureus and Escherichia coli are widely studied as they are important Gram-positive and Gram-negative pathogens respectively and may be resistant to several of the commonly used antimicrobial agents . Lemongrass, Cymbopogon citratus (DC.) Stapf, is an aromatic perennial plant of the family Poaceae. It is widely grown in tropical and subtropical regions and is traditionally used as a herbal tea, a culinary ingredient and a medicinal preparation. The pharmacological properties of

C. citratus are due to volatile and non-volatile phytochemicals, such as citral, geranial, neral, geraniol, myrcene, flavonoids, tannins, phenolic acids and other terpenoid compounds . Chitral, mainly geometric isomers geranial and neural, are considered as one of the major biologically active constituents of lemongrass essential oil. Early studies showed that citral-containing fractions of lemongrass oil exhibited antibacterial activity and later studies confirmed that lemongrass preparations were able to inhibit several pathogenic bacterial species [3]. The antibacterial activity of C. citratus has been assessed by means of essential oils, aqueous preparations, methanolic extracts, ethanolic extracts and other solvent derived fractions. Naik et al. [4] reported activity against several pathogenic bacteria including S. aureus and E. coli. Furthermore, Aiemsaard et al. [5] showed that lemongrass oil and its main constituents could inhibit the growth of bacteria and affect the cellular integrity of S. aureus . Tavares et al. [6] showed that materials obtained from lemongrass showed a measurable antioxidant activity against DPPH radicals. Later studies have confirmed the presence of phenolic and terpenoid constituents in lemongrass extracts and essential oils which are associated with concentration dependent antioxidant effects. Similarly, De Silva et al. [7] reported that lemongrass oil showed a wide range of antibacterial activity against pathogenic bacterial isolates. These findings support the antimicrobial potential of lemongrass, although the magnitude of activity reported varies considerably among studies depending on the origin of the plant, bacterial strain, extraction method, extract concentration and susceptibility-testing procedure. Thus, the same plant may provide aqueous and alcoholic extracts with very different antibacterial activities. Subramaniam et al. [8] reported antibacterial activity of methanolic lemongrass extract while boiled aqueous preparation showed little or no measurable effect under their experimental conditions. Studies of optimization have also shown that recovery of phenolic and volatile constituents from C. citratus can be influenced by solvent composition, extraction temperature, extraction time and plant to solvent ratio [9]. Plant constituents may modulate the activity of antibiotics by increasing membrane permeability, interfering with bacterial efflux systems, disturbing energy metabolism or acting on cellular targets other than those affected by the antibiotic. However, the combination of treatments may result in synergistic, additive, indifferent or antagonistic effects, depending on the concentrations and the microbial strain under examination. Hussain et al. [10] observed the increase in antibacterial activity when C. citratus and Azadirachta indica extracts were mixed in some proportions. Recent studies have also demonstrated that the antimicrobial and antioxidant properties of ethanolic extracts from different Cymbopogon tissues are dependent on their phytochemical composition [11]. Besides its antibacterial activity, C. citratus has attracted attention as a potential source of natural antioxidants. Oxidative stress is the imbalance between the production of reactive oxygen species and antioxidant defence and may be associated with oxidative damage to cellular lipids, proteins and nucleic acids. Phenolic compounds and flavonoids have the ability to reduce oxidative reactions by donating hydrogen atoms or electrons to reactive free radicals [12, 13]. For example, Adonu et al. [14] tested lemongrass essential oil with ciprofloxacin on fluoroquinolone resistant S. aureus and E. coli and found the interaction to vary between isolates showing additive, synergistic and indifferent results. The 2,2-diphenyl-1-picrylhydrazyl radical-scavenging assay is a common method for initial screening of antioxidant activity, offering a simple spectrophotometric measurement of the capacity of a sample to reduce the stable DPPH radical. The reduction of DPPH is accompanied by the disappearance of its purple colour and a corresponding decrease in absorbance, usually measured at around 515–517 nm [15]. Therefore, the comparison at different concentrations of the extracts can give information about the concentration dependent radical scavenging capacity, while ascorbic acid can be used as a reference antioxidant. So, the present study was conducted with the objective to evaluate the antibacterial and antioxidant activities of aqueous and alcoholic extracts of C. citratus.

2 MATERIALS AND METHODS

2.1 Preparation of plant extracts and antibacterial assay

Lemongrass (Cymbopogon citratus) was washed, dried and grounded into powder and extracted separately using distilled water and alcohol [state type and concentration]. The extracts were filtered, concentrated and kept at 4 °C for further use. The antibacterial activity of the aqueous and alcoholic extracts were tested against Staphylococcus aureus and Escherichia coli by agar disc-diffusion method. Fresh bacterial suspensions were adjusted to 0.5 McFarland standards and plated uniformly on Mueller-Hinton agar plates. Sterile discs were placed on plates inoculated with plant extracts. Ciprofloxacin was used as a positive control and 15% DMSO as a negative control [16]. The plates were incubated at 37 °C for 18–24 h, and the diameters of the inhibition zones were measured in mm.

2.2 Combined antibacterial activity with ciprofloxacin

The combined antibacterial activity of the plant extracts and ciprofloxacin was determined by disc diffusion method. The treatments tested were: ciprofloxacin alone, aqueous extract with ciprofloxacin, alcoholic extract with ciprofloxacin, positive control and 15% DMSO negative control. Discs with the treatment were deposited on Mueller-Hinton agar plates inoculated with S. aureus or E. coli. Inhibition zones were measured in millimeters after incubation at 37 °C for 18-24 h [17]. The activity of each extract-ciprofloxacin combination was compared with ciprofloxacin alone.

2.3 DPPH radical-scavenging assay

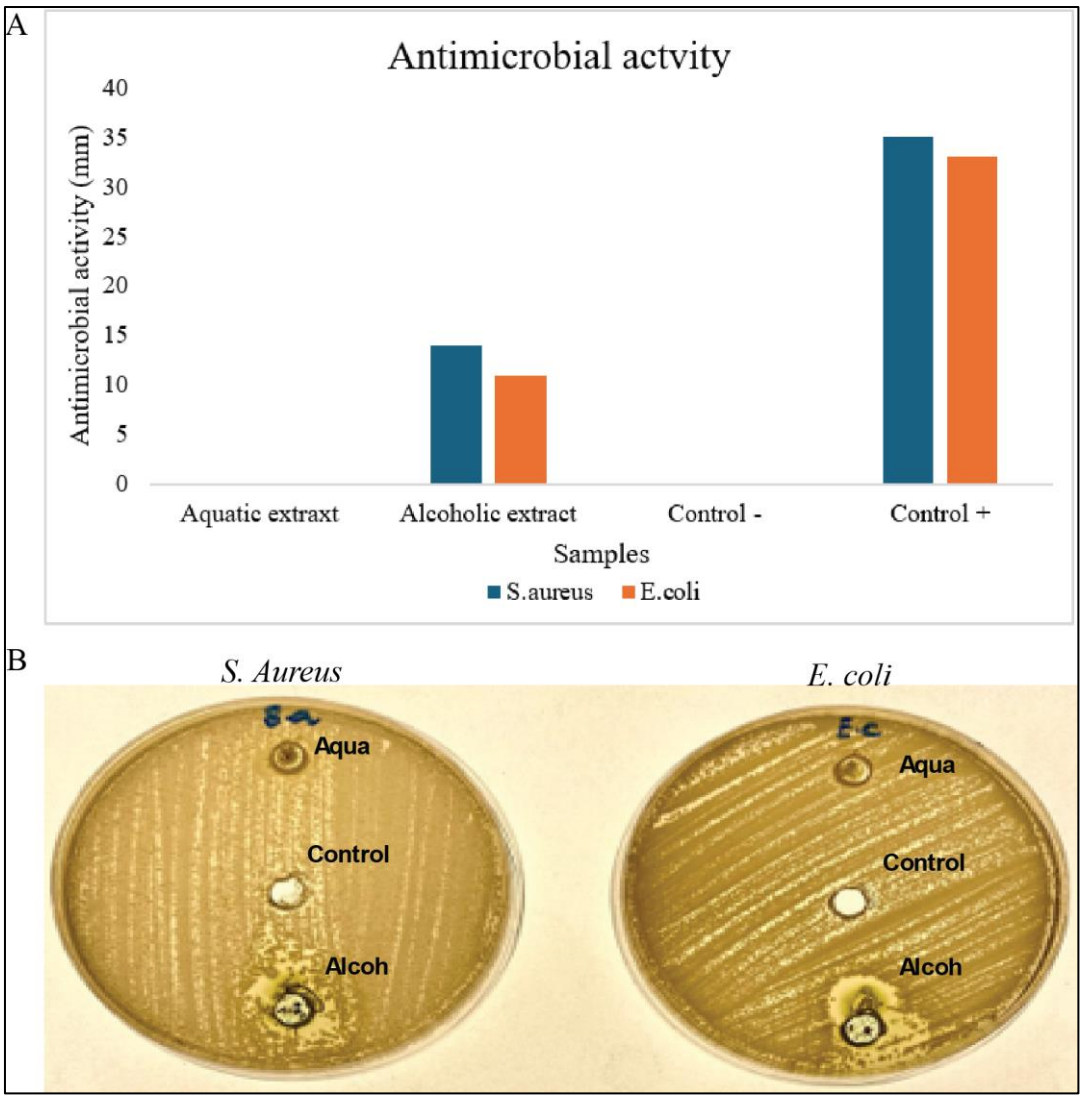
The antioxidant activities of the aqueous and alcoholic lemongrass extracts were evaluated by DPPH radical-scavenging assay. Solutions of the extracts were prepared at concentrations of 10, 20, 40, 80 and 100 mg/mL. Ascorbic acid was used as standard antioxidant. Each sample was mixed with freshly-prepared DPPH solution in a 96-well microplate and incubated in the dark at room temperature for (20–30) min. The absorbance was read at 517 nm. The DPPH control absorbance was 0.8 that means 0% of radical-scavenging activity. Radical scavenging activity was determined by:

$$\text{RSA (\%)} = \frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \times 100$$

where $A_{control}$ is the absorbance of the DPPH control and A_{sample} is the absorbance of the tested sample. All experiments were carried out in triplicates and results are expressed as mean ± standard deviation where replicate measurements were available. [18,19].

3 RESULTS

3.1 Antimicrobial activity of lemongrass extracts



(A) Diameters of the inhibition-zone produced by aqueous and alcoholic extracts of Cymbopogon citratus against Staphylococcus aureus and Escherichia coli. (B) Representative disc-diffusion plates showing antibacterial activity of aqueous extract, alcoholic extract and controls.

Figure 1: Antibacterial activity of lemongrass extracts against test bacteria.

The antimicrobial activity of the aqueous and alcoholic extracts of lemongrass (*Cymbopogon citratus*) was evaluated against *Staphylococcus aureus* and *Escherichia coli* using the disc-diffusion method. The aqueous extract did not produce

a detectable inhibition zone against either bacterial strain, indicating no measurable antibacterial activity under the tested conditions. In contrast, the alcoholic extract produced inhibition zones of 14 mm against *S. aureus* and 11 mm against *E. coli* (Figure 1A).

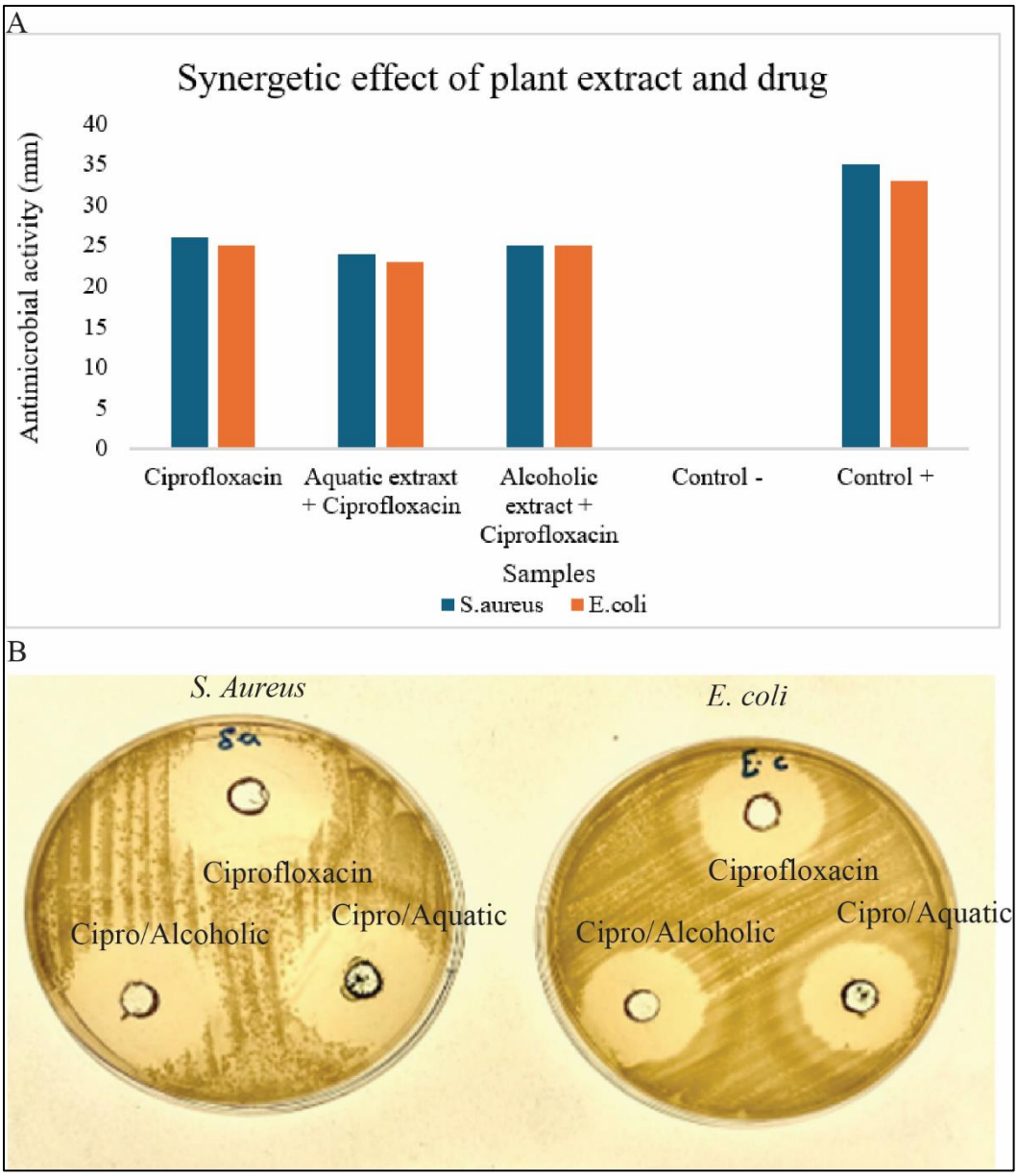
Thus, the activity of the alcoholic extract was more efficient against S. aureus and the zone of inhibition was 3 mm higher than E.coli. The positive control showed zones of inhibition of 35 mm against S. aureus and 33 mm against E. coli. The negative control (15% DMSO) showed no detectable antibacterial activity. Representative agar plates showed no inhibition around the discs of aqueous-extract and clear zones of inhibition around the discs of alcoholic-extract and positive-control (Figure 1B). To summarize, the results showed that the alcoholic extract was more effective than the aqueous extract in recovering the antibacterial constituents of lemongrass.

3.2 Combined antimicrobial activity of lemongrass extracts and ciprofloxacin

The synergistic antibacterial activities of lemongrass extracts and ciprofloxacin against S. aureus and E. coli were also tested. Ciprofloxacin alone showed inhibition zones of 26 mm against S. aureus and 25 mm against E. coli (Figure 2A). The combination of the aqueous extract and ciprofloxacin resulted in inhibition zones of 24 and 23 mm against S. aureus and E. coli, respectively. These values were 2 mm lower than those obtained with ciprofloxacin alone for each organism. The combination of alcoholic extract and ciprofloxacin produced inhibition zones of 25 mm against both species of bacteria (Table 1).

Table 1: Combined antibacterial activity of lemongrass extracts and ciprofloxacin

Treatment	***S. aureus* inhibition zone (mm)**	***E. coli* inhibition zone (mm)**
Ciprofloxacin	26	25
Aqueous extract + ciprofloxacin	24	23
Alcoholic extract + ciprofloxacin	25	25
Negative control, 15% DMSO	ND	ND
Positive control	35	33



(A) Diameter of inhibition zones caused by ciprofloxacin alone and in combination with aqueous or alcoholic lemongrass extracts against S. aureus and E. coli. (B) Representative disc-diffusion plates showing the activities of ciprofloxacin and the extract-ciprofloxacin combinations.

Figure 2: Synergistic antimicrobial activity of lemongrass extracts and ciprofloxacin.

This combination caused a 1 mm reduction against S. aureus and no change against E. coli compared to ciprofloxacin alone. The positive control showed the largest inhibition zones of 35 mm against S. aureus and 33 mm against E. coli and the negative control of 15% DMSO showed no inhibition. The clear inhibition zones around the ciprofloxacin and extract–ciprofloxacin combination discs of the representative agar plates substantiated the quantitative results (Figure 2B). However, the combination of both extracts did not show a greater inhibition zone than that of ciprofloxacin alone. Thus, no clear enhancement of the activity of ciprofloxacin in synergy was observed on the basis of disc-diffusion measurements only under the conditions tested. The alcoholic extract maintained Ciprofloxacin activity better than the aqueous extract, especially against E. coli.

3.3 DPPH radical-scavenging activity

The antioxidant activity of the lemongrass extracts was determined by the DPPH radical-scavenging assay at concentrations ranging from 10 to 100 mg/mL. The negative-control DPPH showed an absorbance of 0.8 which corresponded to 0% radical scavenging activity. The radical scavenging activity was calculated using the equation:

$$\text{RSA (\%)} = \frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \times 100$$

The alcoholic extract showed a moderate radical scavenging activity in the range of 20–100 mg/mL concentrations (Figure 3). The highest activity was observed at 100 mg/mL with an RSA value of 62.50%. At 80 mg/mL the activity was decreased to 56.25% and it was 53.75% at 40 and 20 mg/mL. At 10 mg/ml no radical-scavenging activity was detectable. Antioxidant activity of the aqueous extract was much weaker than the alcoholic extract. The RSA values were 18.75 and 12.50 % at 100 and 80 mg/mL, respectively (Table 2).

Table 2: DPPH radical-scavenging activity of lemongrass extracts and ascorbic acid.

Sample	Concentration(mg/mL)	RSA %	RSA %	Activity level
Ethanol	100	0.625	62.50%	Moderate
	80	56.25	56.25	Moderate
	40	53.75	53.75	Moderate
	20	53.75	53.75	Moderate
	10	0	0	No RSA
Water	100	0.1875	18.75%	Weak
	80	12.5	12.5	Weak
	40	0	0	No RSA
	20	0	0	No RSA
	10	0	0	No RSA
	100	87.5	87.5	Very strong
Ascorbic acid	80	75	75	strong
	40	67.5	67.5	moderat
	20	66.25	66.25	moderat
	10	0	0	No RSA

No activity was observed at 40, 20 and 10 mg/mL. The results showed that alcoholic solvent was more effective than water in extracting antioxidant compounds in lemongrass. The reference antioxidant ascorbic acid showed the highest radical-scavenging activity at all active concentrations. The RSA was found to be 87.50%, 75.00%, 67.50% and 66.25% at 100, 80, 40 and 20 mg/mL, respectively.

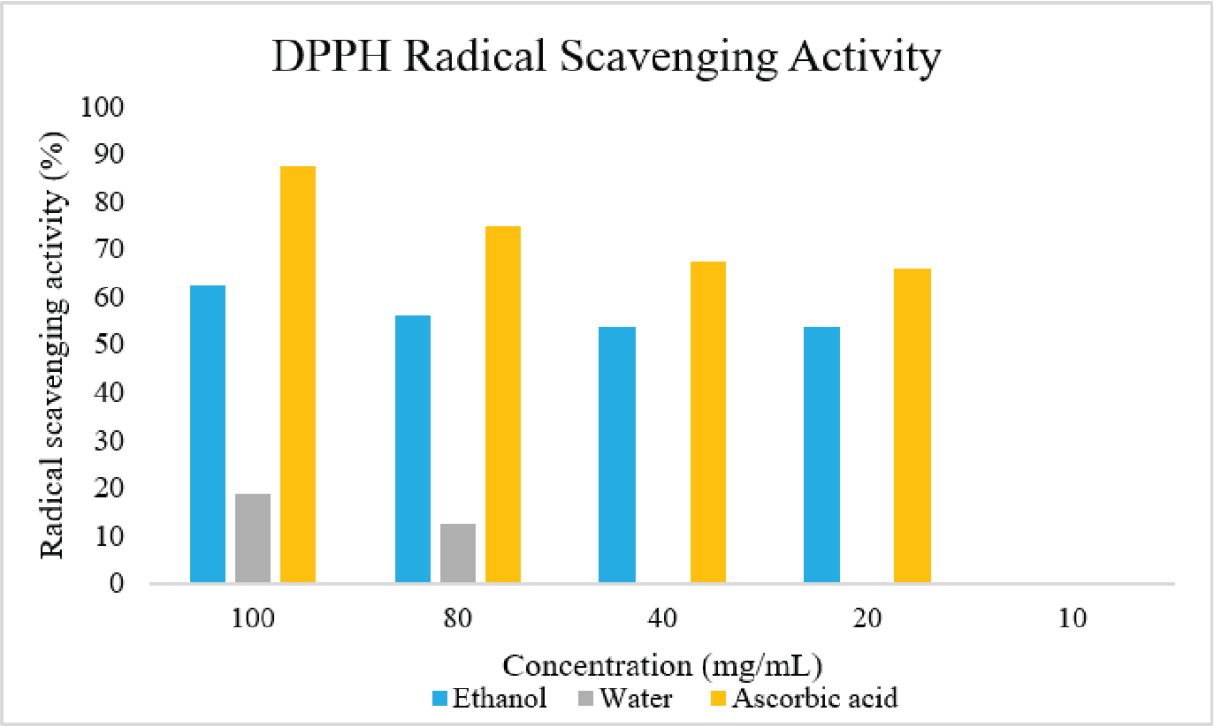


Figure 3: DPPH radical-scavenging activity of lemongrass extracts

Radical-scavenging activity of the alcoholic and aqueous extracts at concentrations of 10–100 mg/mL, with ascorbic acid used as the reference antioxidant.

No activity was seen at 10 mg/mL, however. At 100 mg/mL, the radical-scavenging activity was in the order of ascorbic acid (87.50%) > alcoholic extract (62.50%) > aqueous extract (18.75%). The qualitative appearance of microplate supported the calculated antioxidant activities. In the wells with ascorbic acid and alcoholic extract, there was a more pronounced loss of DPPH colour, while the wells with the aqueous extract showed more of the original DPPH colour, in agreement with their relatively weak scavenging activity (Figure 4). The alcoholic extract showed moderate antioxidant potential while the aqueous extract showed weak activity.

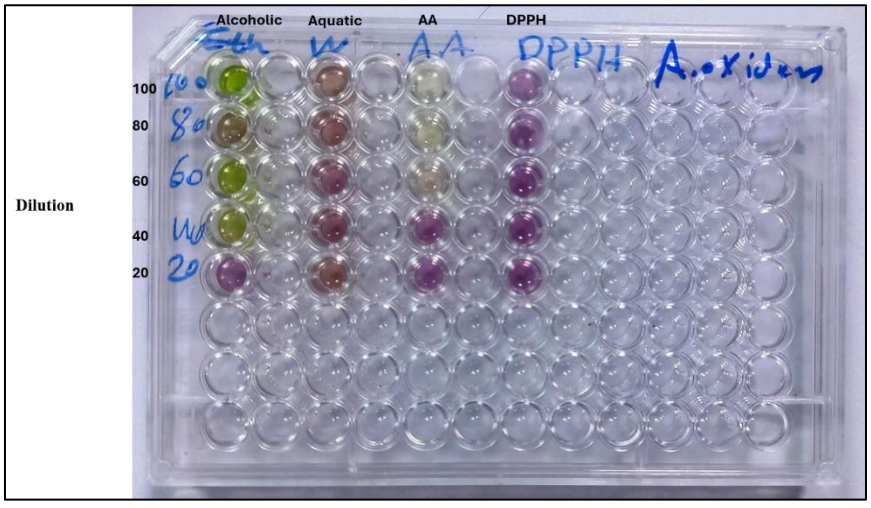


Figure 4: Representative microplate used for the DPPH radical-scavenging assay.

Changes in DPPH colour following treatment with alcoholic extract, aqueous extract, and ascorbic acid at different concentrations. Greater discoloration indicates stronger radical-scavenging activity.

4 DISCUSSION

Lemongrass (Cymbopogon citratus) is a major medicinal plant which contains bioactive compounds that have shown potential antibacterial and antioxidant properties. The present study compares the antibacterial and antioxidant activities of aqueous and alcoholic lemongrass extracts and evaluates whether their combination with ciprofloxacin enhances antibacterial activity. The activity of the extracts against Staphylococcus aureus and Escherichia coli was determined using the agar disc-diffusion method while the combined activity was determined by comparing the extract–ciprofloxacin treatments with ciprofloxacin alone. The antioxidant activity was determined by DPPH radical scavenging assay at the concentration of 10 to 100 mg/mL, using ascorbic acid as reference antioxidant. The alcoholic extract showed inhibition zones of 14 mm against S. aureus and 11 mm against E. coli while the aqueous extract showed no detectable antibacterial activity, suggesting that alcohol extracted the antibacterial constituents more efficiently than water. None of the extracts enhanced the activity of ciprofloxacin, as the inhibition zones obtained from the combination of the extract and ciprofloxacin were equal or smaller than those obtained from ciprofloxacin alone. These interactions are therefore termed non-enhancing rather than synergistic. The alcoholic extract also showed greater antioxidant activity than the aqueous extract with 62.50% of radical scavenging activity at 100 mg/mL compared to 18.75% of the aqueous extract but less than ascorbic acid (87.50%). These results are consistent with Subramaniam et al. [20] who demonstrated that extracts of lemongrass obtained from organic-solvents had a more significant antibacterial activity than aqueous preparations. Onawunmi et al. [21] reported that citral-related constituents were major contributors to antibacterial properties of lemongrass. The lemongrass oil also showed inhibition of S. aureus and E. coli by Naik et al. [22]. The susceptibility of S. aureus in the present study is higher than that reported by Aiemsaard et al. [23], which may be due to the disruption of the cellular integrity of S. aureus by lemongrass oil and its main constituents. Wahyuni et al. [24] demonstrated that antimicrobial and antioxidant activities of ethanolic Cymbopogon extracts are dependent on plant tissue, phytochemical composition, and test organism. Contrary to the present findings, Adonu et al. [25] reported additive or synergistic effects between lemongrass essential oil and ciprofloxacin against selected resistant bacterial isolates; however, differences in extract type, bacterial strain, concentration and interaction-assessment method may account for the variation. Cheel et al. [26] identified several antioxidant and free-radical-scavenging compounds in C. citratus, which may support the greater DPPH activity of the alcoholic extract. One of the major strengths of this study was the simultaneous comparison of aqueous and alcoholic extracts for antibacterial, antibiotic-combination and antioxidant activities against both Gram positive and Gram negative bacteria. However, the study was limited by the use of only two bacterial species, the use of inhibition-zone measurements, the lack of phytochemical characterization, and the lack of MIC, MBC and fractional inhibitory concentration index analyses. In future studies, identification of active constituents by GC–MS or LC–MS, determination of MIC and MBC values, confirmation of antibiotic interactions by checkerboard and time-kill assays, use of resistant clinical isolates, and validation of antioxidant activity by complementary assays such as ABTS, FRAP, and total phenolic-content analysis are suggested.

5 CONCLUSION

The present study revealed that the alcoholic extract of lemongrass (Cymbopogon citratus) showed higher antibacterial and antioxidant activities than aqueous extract. The alcoholic extract inhibited both Staphylococcus aureus and Escherichia coli. The aqueous extract showed no antibacterial activity under the conditions tested. However, neither extract showed an increase in the antibacterial activity of ciprofloxacin indicating that there was no evident synergy in the disc-diffusion assay. The alcoholic extract also exhibited moderate DPPH radical scavenging activity but was less active than ascorbic acid. In general, alcoholic extraction seems to be more appropriate for the recovery of biologically active constituents from lemongrass. Further studies including phytochemical characterization, MIC and MBC determination, checkerboard and time-kill assays and additional antioxidant tests are required to confirm its therapeutic potential.

REFERENCES

[1] Antimicrobial Resistance Collaborators. Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. Lancet. 2022;399(10325):629–655. doi:10.1016/S0140-6736(21)02724-0.

[2] Onawunmi GO, Yisak WA, Ogunlana EO. Antibacterial constituents in the essential oil of *Cymbopogon citratus* (DC.) Stapf. Journal of Ethnopharmacology. 1984;12(3):279–286. doi:10.1016/0378-8741(84)90057-6.

[3] Cheel J, Theoduloz C, Rodríguez J, Schmeda-Hirschmann G. Free radical scavengers and antioxidants from lemongrass, *Cymbopogon citratus* (DC.) Stapf. Journal of Agricultural and Food Chemistry. 2005;53(7):2511–2517. doi:10.1021/jf0479766.

[4] Naik MI, Fomda BA, Jaykumar E, Bhat JA. Antibacterial activity of lemongrass (*Cymbopogon citratus*) oil against some selected pathogenic bacteria. Asian Pacific Journal of Tropical Medicine. 2010;3(7):535–538. doi:10.1016/S1995-7645(10)60129-0.

[5] Aiemsaard J, Aiumlamai S, Aromdee C, Taweechaisupapong S, Khunkitti W. The effect of lemongrass oil and its major components on clinical isolate mastitis pathogens and their mechanisms of action on *Staphylococcus aureus* DMST 4745. Research in Veterinary Science. 2011;91(3):e31–e37. doi:10.1016/j.rvsc.2011.01.012.

[6] Tavares F, Costa G, Francisco V, et al. *Cymbopogon citratus* industrial waste as a potential source of bioactive compounds. Journal of the Science of Food and Agriculture. 2015;95(13):2652–2659. doi:10.1002/jsfa.6999.

[7] De Silva BCJ, Jung WG, Hossain S, Wimalasena SHMP, Pathirana HNKS, Heo GJ. Antimicrobial property of lemongrass (*Cymbopogon citratus*) oil against pathogenic bacteria isolated from pet turtles. Laboratory Animal Research. 2017;33(2):84–91. doi:10.5625/lar.2017.33.2.84.

[8] Subramaniam G, Yew XY, Sivasamugham LA. Antibacterial activity of *Cymbopogon citratus* against clinically important bacteria. South African Journal of Chemical Engineering. 2020;34:26–30. doi:10.1016/j.sajce.2020.05.010.

[9] Muala WCB, Desobgo ZSC, Jong NE. Optimization of extraction conditions of phenolic compounds from *Cymbopogon citratus* and evaluation of phenolics and aroma profiles of extract. Heliyon. 2021;7(4):e06744. doi:10.1016/j.heliyon.2021.e06744.

[10] Hussain S, Javed W, Tajammal A, et al. Synergistic antibacterial screening of *Cymbopogon citratus* and *Azadirachta indica*: phytochemical profiling and antioxidant and hemolytic activities. ACS Omega. 2023;8(19):16600–16611. doi:10.1021/acsomega.2c06785.

[11] Cortes-Torres AG, López-Castillo GN, Marín-Torres JL, et al. *Cymbopogon citratus* essential oil: extraction, GC–MS, phytochemical analysis, antioxidant activity, and in silico molecular docking for protein targets related to CNS. Current Issues in Molecular Biology. 2023;45(6):5164–5179. doi:10.3390/cimb45060328.

[12] Wahyuni DK, Kharisma VD, Murtadlo AAA, et al. The antioxidant and antimicrobial activity of ethanolic extract in roots, stems, and leaves of three commercial *Cymbopogon* species. BMC Complementary Medicine and Therapies. 2024;24:272. doi:10.1186/s12906-024-04573-4.

[13] Luang-In V, Saengha W, Karirat T, Senakun C, Siriamornpun S. Phytochemical profile of *Cymbopogon citratus* (DC.) Stapf lemongrass essential oil from northeastern Thailand and its antioxidant and antimicrobial attributes and cytotoxic effects on HT-29 human colorectal adenocarcinoma cells. Foods. 2024;13(18):2928. doi:10.3390/foods13182928.

[14] Adonu C, Onwusoba R, Onyi P, Ibeabuchi A, Omeh R. Potentiation of antibacterial activity of ciprofloxacin by essential oil of *Cymbopogon citratus* against fluoroquinolone-resistant *Staphylococcus aureus* and *Escherichia coli*. Journal of Pharmaceutical Research International. 2023;35(24):34–41. doi:10.9734/jpri/2023/v35i247425.

[15] Brand-Williams W, Cuvelier ME, Berset C. Use of a free radical method to evaluate antioxidant activity. LWT—Food Science and Technology. 1995;28(1):25–30. doi:10.1016/S0023-6438(95)80008-5.

[16] Clinical and Laboratory Standards Institute. *Performance Standards for Antimicrobial Disk Susceptibility Tests*. 14th ed. CLSI standard M02. Wayne, PA: Clinical and Laboratory Standards Institute; 2024.

[17] Adonu C, Onwusoba R, Onyi P, Ibeabuchi A, Omeh R. Potentiation of antibacterial activity of ciprofloxacin by essential oil of *Cymbopogon citratus* against fluoroquinolone-resistant *Staphylococcus aureus* and *Escherichia coli*. Journal of Pharmaceutical Research International. 2023;35(24):34–41. doi:10.9734/jpri/2023/v35i247425.

[18] Brand-Williams W, Cuvelier ME, Berset C. Use of a free radical method to evaluate antioxidant activity. LWT–Food Science and Technology. 1995;28(1):25–30. doi:10.1016/S0023-6438(95)80008-5.

[19] Cheel J, Theoduloz C, Rodríguez J, Schmeda-Hirschmann G. Free radical scavengers and antioxidants from lemongrass, Cymbopogon citratus (DC.) Stapf. Journal of Agricultural and Food Chemistry. 2005;53(7):2511–2517. doi:10.1021/jf0479766.

[20] Subramaniam G, Yew XY, Sivasamugham LA. Antibacterial activity of Cymbopogon citratus against clinically important bacteria. South African Journal of Chemical Engineering. 2020;34:26–30. doi:10.1016/j.sajce.2020.05.010.

[21] Onawunmi GO, Yisak WA, Ogunlana EO. Antibacterial constituents in the essential oil of Cymbopogon citratus (DC.) Stapf. Journal of Ethnopharmacology. 1984;12(3):279–286. doi:10.1016/0378-8741(84)90057-6.

[22] Naik MI, Fomda BA, Jaykumar E, Bhat JA. Antibacterial activity of lemongrass (Cymbopogon citratus) oil against some selected pathogenic bacteria. Asian Pacific Journal of Tropical Medicine. 2010;3(7):535–538. doi:10.1016/S1995-7645(10)60129-0.

[23] Aiemsaard J, Aiumlamai S, Aromdee C, Taweechaisupapong S, Khunkitti W. The effect of lemongrass oil and its major components on clinical isolate mastitis pathogens and their mechanisms of action on Staphylococcus aureus. Research in Veterinary Science. 2011;91(3):e31–e37. doi:10.1016/j.rvsc.2011.01.012.

[24] Wahyuni DK, Kharisma VD, Murtadlo AAA, et al. The antioxidant and antimicrobial activity of ethanolic extract in roots, stems, and leaves of three commercial Cymbopogon species. BMC Complementary Medicine and Therapies. 2024;24:272. doi:10.1186/s12906-024-04573-4.

[25] Adonu C, Onwusoba R, Onyi P, Ibeabuchi A, Omeh R. Potentiation of antibacterial activity of ciprofloxacin by essential oil of Cymbopogon citratus against fluoroquinolone-resistant Staphylococcus aureus and Escherichia coli. Journal of Pharmaceutical Research International. 2023;35(24):34–41. doi:10.9734/jpri/2023/v35i247425.

[26] Cheel J, Theoduloz C, Rodríguez J, Schmeda-Hirschmann G. Free radical scavengers and antioxidants from lemongrass, Cymbopogon citratus (DC.) Stapf. Journal of Agricultural and Food Chemistry. 2005;53(7):2511–2517. doi:10.1021/jf0479766.