ANTIBACTERIAL ACTIVITY AND MOLECULAR CHARACTERISTICS OF INDIAN OLIBANUM (*BOSWELLIA SERRATA)* PHYTOCHEMICALS: AN IN SILICO APPROACH

VAKAYIL, R.[1] – KABEERDASS, N.[1] – MURUGESAN, K.[2] – SHANMUGAM, G.[3] – RAMASAMY, S.[4] – MATHANMOHUN, M.[1*]

[1]*Department of Microbiology, Muthayammal College of Arts and Science, Rasipuram 637408, Namakkal DT., Tamil Nadu, India*

[2]*Department of Microbiology, Faculty of Medicine, Quest International University, Malaysia*

[3]*Department of Biotechnology, Yeungnam University, Gyeongsan, Gyeongbuk 38541, South Korea*

[4]*Tamil Nadu State Council for Science & Technology, Chennai, Tamil Nadu, India*

**Corresponding author*
e-mail: mmaghimaa@gmail.com, maghimaam@gmail.com; ORCID: 0000-0002-9043-435X

(Received 18th Aug 2021; accepted 23rd Nov 2021)

Abstract. An unhealthy community is a reservoir for the global threat of Nosocomial infection. Rapidly escalating drug resistance and nosocomial infections resulting from the search for a novel drug is a tough challenge to upcoming researchers. Indian olibanum extract is held in high regard in the field of traditional medicines. To evaluate the antibacterial properties of *B. serrata* aqueous and hydroethanolic extract was taken with an in silico approach using Autodock vena tool. The nosocomial pathogens were detected from wound and skin samples in the Hospitals and from around Namakkal. Among the gram-negative nosocomial pathogen *Klebsiella oxytoca* and gram-positive *Staphylococcus aureus* were branded by microscopic and biochemical profiling. In addition, the susceptibility and resistance to antibiotics were explored for *K. oxytoca* and *S. aureus* in the case of tetracycline (21 mm and 28 mm), chloramphenicol (23 mm and 16 mm), and gentamycin (14 mm and 21 mm) respectively. The seven bioactive compounds were attained by GCMS. The inhibition zone of 18 mm at 60 µg deliberation for both the isolates viz *K. oxytoca* and *S. aureus.* In silico approach of phyto-bioactives with Beta-lactamase (AmpC) was investigated by Autodock vena tool. In silico Molecular docking approach examined the binding energy as -7.6 (kcal/mol) for Cholan-24-oic acid, 3,12-bis(acetyloxy) followed by Pyrene, hexadecahydro- -7.5 (kcal/mol), 5(1H)-Azulenone, 2,4,6,7,8,8a-hexahydro-3,8-dimethyl-4-(1-methylethylidene)-, (8S-cis)- -6.7 (kcal/mol). The conclusion of the finding is that phyto-bioactives of *B. serrata* also promote natural healing and antibacterial potential.
Keywords: *bioactives, phyto-extracts, natural healing, nosocomial, molecular docking*

Introduction

Hospital-acquired nosocomial infection and drug resistance is a saddle in the health, medical field and this is a global health crisis (Patil and Rathod, 2020; Vakayil et al., 2021b). The antibiotic drugs are currently regained by the bioactive compounds of plants (Ansari et al., 2019) in this approach, the *B. serrata* achieves its significant place and exploring its usefulness towards antibacterial activity. The ancient (pre-historical) times used Boswellic acid contain infinite bioactives that are pharmacologically used for therapeutics (Sharma et al., 2016). *B. serrata* was well known in herbal treatment hundred years ago. Boswellic acid consists of two components α and β boswellic acid originating from resin, which is the primary component of *B. serrata*. Resin from the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2002_919929

bark of the tree is rich in antioxidants. B. serrata is commonly known as Indian frankincense or Indian olibanum because the dried exudates from the bark of the tree are an ole-gum-resin. Dried gum looks like lumps or tears and is ivory (yellow and white) in colour. 'Pure incense" is another name for B. serrata derived from the French language. Olibanum means white or cream derived from Arabic languages so it is named as "olibanum". The bioactive compounds offer their effectiveness towards the ailments. In the antique era, the therapeutic value of natural medicine was unknown at global level. In modern days the numerous researcher studies explored the economical and therapeutic significance of this species (Niphadkar et al., 2017). The pharma of plants probed the importance of the species implicit, enormously cultivated medicinal properties wide-ranging of bioactive compounds are obtaining best prognosis (Fan et al., 2021; Sun et al., 2021). According to the agriculture sector, the production of B.serrata is not adequate, but somehow it reduces the virulence of the organism causing disease. Whaterver ailments occur to our body boswellic acid is the right choice (Niphadkar and Rathod, 2018). Thus, the salai gaugal heals inflammation, breathlessness, blood disorders, painful joints, heart, inability, malignants, and stomach upsets. In silico approach such as auto dock vena tool also helps us to briefly clarify the drug molecule and the receptor interactions by three-dimensional structures and its efficacy are exposed in the form of binding energies thus the healing process of an apparent wound (Chou et al., 2017) is preciously and powerfully treated and attained an expectational result by this phytotherapy which was conjoint with metal microparticles.

Methodology

Resin collection

Purchased wrinkled, golden amber-colored *B. serrata* resins from Kolli Hills, Namakkal DT, Tamil Nadu, India. After surface sterilization, it was dried in the shadow and then made into powder for extraction (Vakayil et al., 2021a).

Extraction of B. serrata

10 g of powdered resin was weighed and mixed with 100 ml of hydroethanolic and aqueous solvent in a 250 ml flask. Through the microwave method, it was extracted by placing the beaker on the circular plate. Maintaining the different parameters such as temperature and time the aqueous phase was obtained after filtering via Whatman filter paper no1 (Kumar et al., 2016). After that, the crude was placed in an icebox, and the container was sealed for future analysis.

GC-MS

Samples (solid and liquid) in GC–MS were prepared by dissolving inappropriate solvents (polar and nonpolar). International union of pure and applied chemistry (IUPAC) of the compound, Morphology, Molecular weight (MW), length, and internal diameter all are analyzed using the mass spectral library (NIST software) (Bhutada et al., 2017).

Collection of strains

Sufficient exudates of the wound and skin specimens using sterile needles, containers, and tubes, were procured from chronic wound beds without cross-

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2002_919929

contamination (Ohemu et al., 2018). Nearly twenty samples were collected from different laboratories in Namakkal DT, Tamil Nadu, India. Then sealed aseptically and transported to the laboratory in time (Kabeerdass et al., 2021).

Inoculation and screening

Isolation of the sample is done by inoculating it in their selective media such as MSA, and EMB and incubated at 37 °C for 24 h (Asante-Kwatia et al., 2020). Smear was prepared for gram staining to observe the morphology of the organism. Crystal violet, mordant, alcohol, and safranin are sprinkled one after the other for a minute, dried, and observed under the microscope to note whether it was a gram +ve or gram –ve. To confirm its physiological state some biochemical tests like Methylred, Voges Proskauer, indole, citrate oxidase, urease coagulase, and catalase were done (Vakayil et al., 2019).

Antibiotic sensitivity test

In the MHA plate, both gram-positive (*S. aureus*) and gram-negative (*K. oxytoca*) were streaked in a zig-zag manner on the plate. A circular antibiotic disc (6 mm) was impregnated on the plate (Vahabi et al., 2019*).* The plate was spread with *K. oxytoca* and *S. aureus* (nosocomial pathogens) against a spectrum of drugs such as Meropenem, vancomycin, and tetracycline (Abirami and Maghimaa, 2019).

Antibacterial activity

A diverse concentration of resin crude (20 µg, 40 µg, and 60 µg) was added to each well which was made by the cork Borell of 6 mm, then incubated for 24 h and the MIC values were observed and tabulated (Maghimaa and Alharbi, 2020; Arora et al., 2020; Kabeerdass et al., 2021; Vakayi et al., 2021f).

Ligand preparation

The structural (Schmiech et al., 2019) geometry in GC–MS were observed through the database and some chemical parameters like bond length, ionization energy, radius, efficient charges, strengths were ruled out (Khan et al., 2016). The efficacy of the antibiotics used and the three-dimensional structures of the compounds were identified in PDF format via molecular docking.

Molecular docking

Docking was used to calculate the protein-ligand chemistry (Taghizadeh et al., 2018), torsion of the atom, van der Waals forces, its positions, the conjoining of the hydrogen atom (Du et al., 2015) between the un polar structure through the in silico mol soft tool Autodock vena (Bairwa and Jachak, 2016; Bolbolian et al., 2018; Vakayil et al., 2021d; Gaillard, 2018; Baburam et al., 2021).

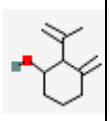
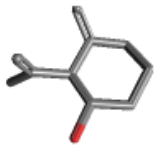
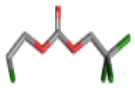
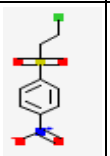
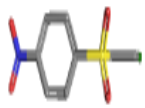
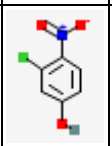
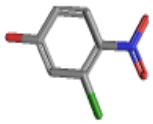
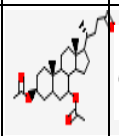
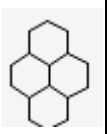
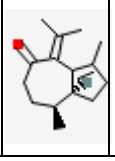
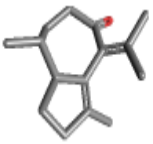
Results

GC–MS analysis

A stream of seven plant-derived compounds in the hydroethanolic extract from the crude of *B. serrata* via GC-MS is shown in *Table 1*.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2002_919929

Table 1. *Phyto bioactive Compounds identified through GC–MS analysis of B. serrata*

S. No	Name of the compound	Retention time	Molecular formula	Molecular weight	Peak area	PUB CHEM ID	2D structure	3D structure
1.	o-Mentha-1(7),8-dien-3-ol	21.352	$C_{10}H_{16}O$	152.23 g/mol	2.67	564552		
2.	Carbonic acid, 2-chloroethyl 2,2,2-trichloroethyl ester	22.063	$C_5H_6Cl_4O_3$	255.9 g/mol	1.26	87646995		
3.	Benzene, 1-[(2-chloroethyl)sulfonyl 4-nitro	22.130	$C_8H_8ClNO_4S$	249.67 g/mol	1.07	80935		
4.	3-chloro-4-nitrophenol	26.318	$C_6H_4ClNO_3$	173.55 g/mol	1.62	10283		
5.	Cholan-24-oic acid, 3,12-bis(acetyloxy)	26.729	$C_{29}H_{46}O_6$	490.7 g/mol	8.88	21140628		
6.	Pyrene, hexadecahydro-	26.840	$C_{16}H_{26}$	218.38 g/mol	12.13	75524		
7.	5(1H)-Azulenone, 2,4,6,7,8,8a-hexahydro-3,8-dimethyl-4-(1-methylethylidene)-, (8S-cis)-	27.229	$C_{15}H_{22}O$	218.33 g/mol	45.36	91735354		

Observed bioactive compounds in the extract

Bioactive compounds examined were o-Mentha-1(7),8-dien-3-ol, Carbonic acid, 2-chloroethyl 2,2,2-trichloroethyl ester, Benzene, 1-[(2-chloroethyl)sulfonyl 4-nitro, 3-chloro-4-nitrophenol, Cholan-24-oic acid, 3,12-bis(acetyloxy), Pyrene, hexadecahydro-, and 5(1H)-Azulenone, 2,4,6,7,8,8a-hexahydro-3,8-dimethyl-4-(1-methylethylidene)-, (8S-cis)-s, the results are briefly given in *Table 1*. The docking score with the minimal binding energy of Cholan-24-oic acid, 3,12-bis(acetyloxy) shows -7.6 of BF (kcal/mol) with AmpC from *K. oxytoca* is explained in *Table 5*.

Isolation and identification

Dark pink shiny mucoid lactose fermenting colonies were isolated on McConkey agar plate which differ from other commensals. This is an encapsulated gram-negative bacillus that shows positive sign for Indole, Voges Proskauer, urease, citrate, catalase,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2002_919929

and for gram-positive cocci positive results were obtained to VP, Citrate, Urease, catalase, coagulase methyl red, and oxidase.

Antibiotic sensitivity

An extensive spectrum of antibiotics such as tetracycline (30 µg), Chloramphenicol (30 µg)**,** and Gentamycin (10 µg) were effectively used against gram-negative bacilli *K. oxytoca* and also *S. aureus* which is a gram-positive coccus. In this *K. oxytoca* showed a high zone of inhibition (21 mm, and 23 mm) against tetracycline than chloramphenicol when compared with gram-positive bacilli *S. aureus* with a zone of inhibition (28 mm, and 16 mm) the results are presented in *Table 2*.

Table 2. *Antibiotic sensitivity test against the nosocomial pathogens (ZOI in mm)*

Isolates	Tetracycline (30 µg)		Chloramphenicol (30 µg)		Gentamycin (10 µg)	
	ZOI	Inf	ZOI	Inf	ZOI	Inf
Staphylococcus aureus	28	S	16	R	21	S
Klebsiella oxytoca	21	S	23	S	14	R

R – Resistance, I – Intermediate, S – Sensitivity, ZOI – Zone of Inhibition, Inf – Inference Te; Tetracycline: C; Chloramphenicol; Gm: Gentamycin

Antibacterial activity

In the case of resin crude, the aqueous and hydroethanolic extract of the nosocomial pathogen *K. oxytoca* and *S. aureus* shows the highest zone of inhibition of 18 mm at 60 µg concentration. This indicates the susceptibility of pathogens towards the extracts, their MIC values are shown in *Table 3*.

Table 3. *B. serrata shows susceptibility against the nosocomial pathogens*

S. no	Isolates	*B. serrata* resin extracts (ZOI in mm)					
		Aqueous extract (in mcg)			Hydroethanol extract (in mcg)		
		20	40	60	20	40	60
1	*Staphylococcus aureus*	15 ± 1.041	17 ± 0.763	18 ± 0.763	17 ± 0.763	18 ± 0.763	18 ± 0.763
2	*Klebsiella oxytoca*	13 ± 0.557	16 ± 0.771	18 ± 0.763	14 ± 1.041	15 ± 1.04	18 ± 0.763

Data are mean ± SE (n = 3)

Protein-protein interaction

Antibiotic Reference Drugs used for docking are shown in *Table 5*. Nonbonding and bonding interaction of the residues in the active site is shown via docking (*Table 4*). The AmpC from *K. oxytoca* shows a binding affinity at -7.6 (less binding energy) with Cholan-24-oic acid, 3,12-bis(acetyloxy), followed by Pyrene, hexadecahydro- -7.5 (kcal/mol) and 5(1H)-Azulenone, 2,4,6,7,8,8a-hexahydro-3,8-dimethyl-4-(1-methylethylidene)-, (8S-cis)- -6.7 (kcal/mol). Among the Phyto compounds, Cholan-24-oic acid, 3,12-bis(acetyloxy), show a binding affinity -7.6 (kcal/mol), and the reference drug tetracycline also has the same binding affinity -7.6 (kcal/mol) are shown by highlighting in *Table 5*. The binding score and 3D graphical structure are all shown

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2002_919929

below with their CID 21140628 > CID 75524 > CID 91735354 > CID 54675776 in which the color variation shows the binding affinity of the amino acids in *Figures 1-4*.

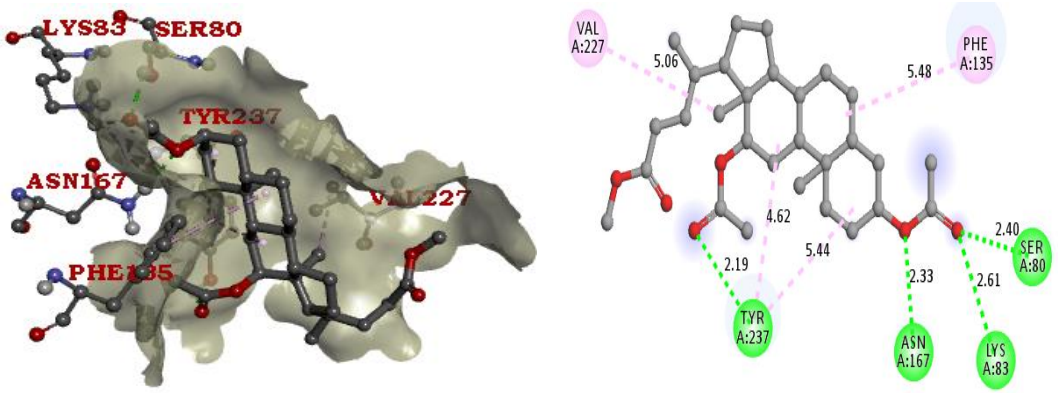


Figure 1. *AmpC K. oxytoco - CID 21140628 docking pose & interaction plot (-7.6 Kcal/mol)*

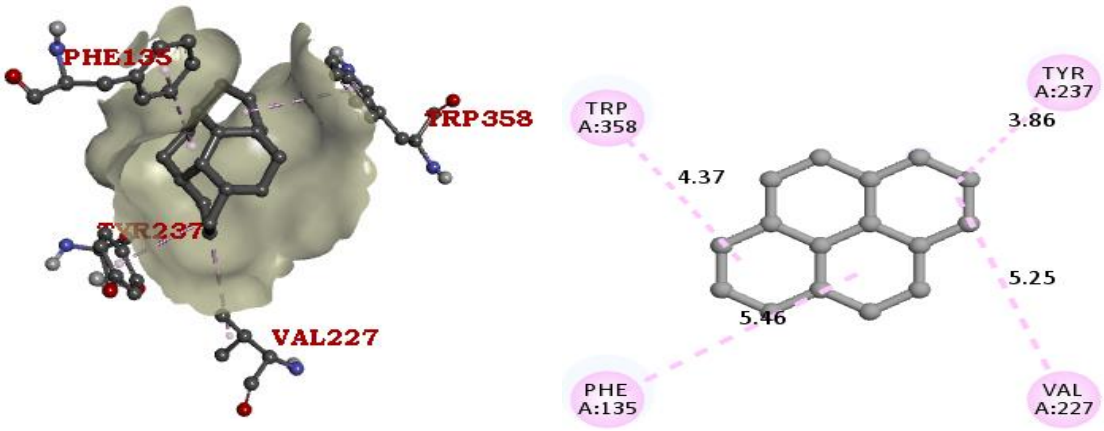


Figure 2. *AmpC K. oxytoco - CID 75524 docking pose & interaction plot (-7.5 Kcal/mol)*

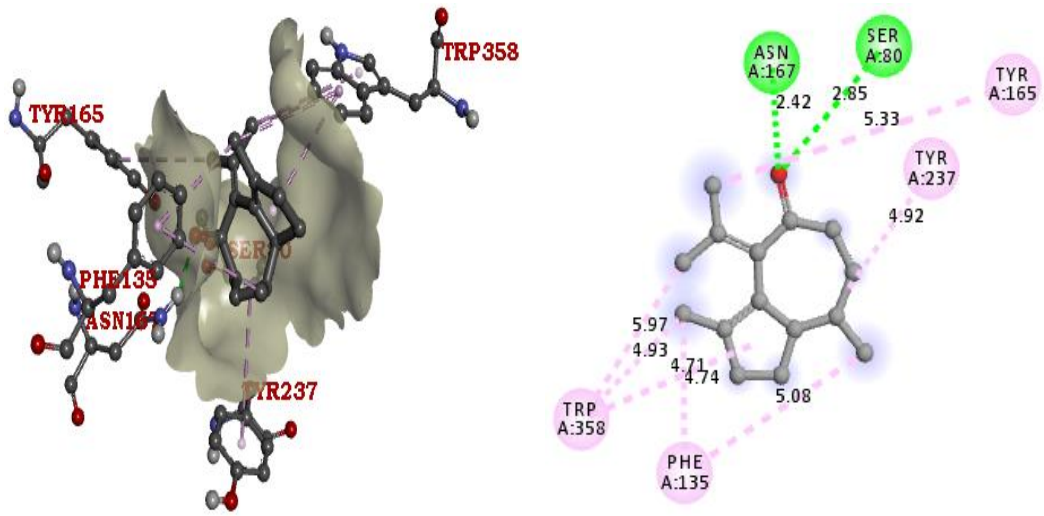


Figure 3. *AmpC K. oxytoco - CID 91735354 docking pose & interaction plot (-6.7 Kcal/mol)*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2002_919929

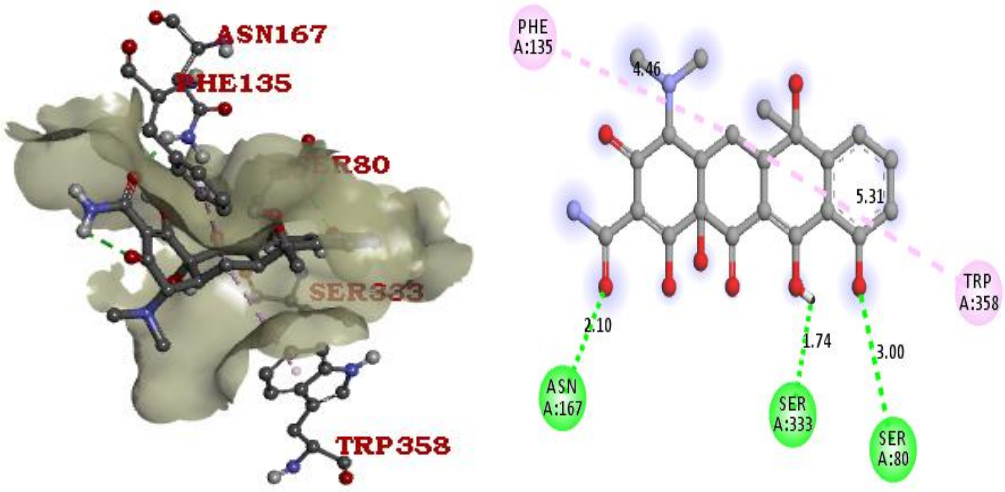


Figure 4. *AmpC K. oxytoco - CID 54675776 docking pose & interaction plot (-7.6 Kcal/mol)*

Table 4. *Docking interaction table for AmpC K. oxytoco ligand complexes*

S. No	Complex name	Bonded interactions	Non bonded interactions	Docking score (-K.Cal/mol)
1.	CID 564552	-	Met306,Leu134,Phe135,Tyr165	-5.4
2.	CID 87646995	Ser80,Ser333	Ser333	-4.5
3.	CID 80935	Asn167,Thr331	Gly305,Ser80,Phe135	-5.8
4.	CID 10283	Ala234,Phe185,Asp233	Leu232,Glu235	-5.2
5.	CID 21140628	Ser80,Lys83,Asn167,Tyr237	Phe135,Val227,Tyr237	-7.6
6.	CID 75524	-	Phe135,Val227,Tyr237,Trp358	-7.5
7.	CID 91735354	Ser80,Asn167	Phe135,Ytr165,Tyr237,Trp358	-6.7
8.	CID 5959	-	Ser333,Tyr237	-6.8
9.	CID 37569	Ser333,Ser80,Val136	Asn167	-6.6
10.	CID 54675776	Ser80,Asn167,Ser333	Phe135,Trp358	-7.6

Table 5. *Docking score of phytocompounds and antibiotic reference drug against AmpC*

Compounds	Binding affinities (kcal/mol) with AmpC from *K. oxytoca*
o-Mentha-1(7),8-dien-3-ol	-5.4
Carbonic acid, 2-chloroethyl 2,2,2-trichloroethyl ester	-4.5
Benzene, 1-[(2-chloroethyl)sulfonyl 4-nitro	-5.8
3-chloro-4-nitrophenol	-5.2
Cholan-24-oic acid, 3,12-bis(acetyloxy)	-7.6
Pyrene, hexadecahydro-	-7.5
5(1H)-Azulenone, 2,4,6,7,8,8a-hexahydro-3,8-dimethyl-4-(1-methylethylidene)-, (8S-cis)-	-6.7
Chloramphenicol	-6.8
Gentamycin	-6.6
Tetracyclin	-7.6

Discussion

Nosocomial drug resistance developed a rigorous crisis in health and hospital care, intensifying morbidity, fatality, extent the reside and raise the costs of healthcare (Exner et al., 2017). The nosocomial drug resistance exhibited variations among hospitals

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2002_919929

around the globe. The majority of the infections caused by bacteria are resistant to multiple drugs (Asres et al., 2017). This study explored the drug resistance of *S. aureus* and *K. oxytoca* from nosocomial infections. Similar findings were explored by other studies (Vakayil et al., 2020). This determined that drug resistance to nosocomial pathogens is a major health issue. A lofty number of patients, deprived infection management practices, self-therapeutic medication, maltreatment, improper overprescription, extended hospitalization, and deviation in aseptic dealings may be the causes. The crude of the *B. serrata* resin shows its inhibitory action against the nosocomial pathogen *K. oxytoca* (Jamwal and Sharma, 2018). *B. serrata* consists of immense therapeutic bioactive that diverge by the extraction process and compound nature. The small organic chemical compound obtained by microwave extraction shows its effective role in antibacterial, antifungal, ulcer healing, and control of nosocomial infection (Beghelli et al., 2017). Through GC-MS analysis the effective bioactive compound cholan-24-oic acid, 3,12-bis(acetyloxy) (Vakayil et al., 2021c; Perleberg et al., 2018) was extracted and proved its susceptibility character against tetracycline, chloramphenicol, and gentamycin via in silico tool (Siemoneit et al., 2017).

Conclusion

The phytochemicals in *B. serrata* are efficient in repairing the wound. Morphology and biochemical changes occur in the wound which leads to scar formation after exposure to the *B. serrata* extract. Protein-protein interaction of the nosocomial pathogen (*K. oxytoca*) against tetracycline, chloramphenicol, and gentamycin showed less effectiveness compared with the action of *B. serrata* extract. This proves that *B. serrata* is a cheap, eco-friendly, and safe remedy due to the rich source of antioxidant properties. In the future, it might be produced on a large scale and act as a medication for curing chronic ulcers.

Acknowledgments. The corresponding author is thankful for the financial support from Tamil Nadu State Council for Science & Technology (TNSCST), DOTE Campus, Chennai (S&T Project: TNSCST/STP-PRG/AR/2018-2019), and DST–FIST Centralized laboratory, Muthayammal College of Arts & Science, Rasipuram, Namakkal Dt. Tamil Nadu, India for executing this work.

Conflict of interests. The authors declare no conflict of interests with this research.

REFERENCES

[1] Abirami, K., Maghimaa, M. (2019): Phytochemical screening and bioactivity of Zingiber officinale to combat the multidrug-resistant bacterial pathogens using foldscope. – Uttar Pradesh Journal of Zoology 11: 67-74.

[2] Ansari, S., Bari, A., Ullah, R., Mathanmohun, M., Veeraraghavan, V. P., Sun, Z. (2019): Gold nanoparticles synthesized with Smilax glabra rhizome modulates the anti-obesity parameters in high-fat diet and streptozotocin induced obese diabetes rat model. – Journal of Photochemistry and Photobiology B: Biology 201: 111643. https://doi.org/10.1016/j.jphotobiol.2019.111643.

[3] Arora, K., Tomar, P. C., Kumari, P., Kumari, A. (2020): Medicinal alternative for chikungunya cure: a herbal approach. – J Microbiol Biotechnol Food Sci. 9: 970-8.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2002_919929

[4] Asante-Kwatia, E., Mensah, A. Y., Baidoo, M. F. (2020): Analgesic and Anti-Inflammatory Effect of Ghanaian Medicinal Plants. – In: Hassan, B. (ed.) Medicinal Plants - Use in Prevention and Treatment of Diseases. IntechOpen, London, pp. 3-16.
[5] Asres, G. S., Legese, M. H., Woldearegay, G. M. (2017): Prevalence of multidrug resistant bacteria in postoperative wound infections at Tikur Anbessa specialized hospital, Addis Ababa, Ethiopia. – Arch. Med. 9(4): 1-9.
[6] Baburam, S., Ramasamy, S., Shanmugam, G., Mathanmohun, M. (2021): Quorum Sensing Inhibitory Potential and Molecular Docking Studies of *Phyllanthus emblica* Phytochemicals Against *Pseudomonas aeruginosa*. – Appl Biochem Biotechnol. https://doi.org/10.1007/s12010-021-03683-w.
[7] Bairwa, K., Jachak, S. M. (2016): Nanoparticle formulation of 11-keto-Î²-boswellic acid (KBA): anti-inflammatory activity and in vivo pharmacokinetics. – Pharm Biol. 54(12): 2909-2916.
[8] Beghelli, D., Isani, G., Roncada, P., Andreani, G., Bistoni, O., Bertocchi, M., Lupidi, G., Alunno, A. (2017): Antioxidant and ex vivo immune system regulatory properties of Boswellia serrata extracts. – Oxidative Medicine and Cellular Longevity. DOI: 10.1155/2017/7468064.
[9] Bhutada, S. A., Farhan, M. M., Dahikar, S. B. (2017): Preliminary phytochemical screening and antibacterial activity of resins of Boswellia serrata Roxb. – J Pharmacogn Phytochem. 6: 182-5.
[10] Bolbolian, S., Bozorgmehr, M. R., Morsali, A. (2020): Acetyl-11-keto-β-boswellic acid derivatives effects on 5-lipoxygenase: in silico viewpoint. – Journal of Molecular Graphics and Modelling 94: 107464.
[11] Chou, Y. C., Suh, J. H., Wang, Y., Pahwa, M., Badmaev, V., Ho, C. T., Pan, M. H. (2017): Boswellia serrata resin extract alleviates azoxymethane (AOM)/dextran sodium sulfate (DSS)-induced colon tumorigenesis. – Mol Nutr Food Res. 61: 1600984.
[12] Du, Z., Liu, Z., Ning, Z., Liu, Y., Song, Z., Wang, C., Lu, A. (2015): Prospects of boswellic acids as potential pharmaceutics. – Planta Med. 81:259-71.
[13] Exner, M., Bhattacharya, S., Christiansen, B., Gebel, J., Goroncy-Bermes, P., Hartemann, P., Heeg, P., Ilschner, C., Kramer, A., Larson, E., Merkens, W. (2017): Antibiotic resistance: what is so special about multidrug-resistant Gram-negative bacteria? – GMS Hygiene and Infection Control. DOI: 10.3205/dgkh000290.
[14] Fan, Y., Maghimaa, M., Chinnathambi, A., Alharbi, S. A., Veeraraghavan, V. P., Mohan, S. K., Hussain, S., Rengarajan, T. (2021): Tomentosin reduces behavior deficits and neuroinflammatory response in MPTP-induced Parkinson's disease in mice. – Journal of Environmental Pathology, Toxicology and Oncology 40(1).
[15] Gaillard, T. (2018): Evaluation of AutoDock and AutoDock Vina on the CASF 2013benchmark. – J. Chem. Inf. Model. 58: 1697-1706. DOI: 10.1021/acs.jcim.8b00312.
[16] Jamwal, S., Sharma, S. (2018): Vascular endothelium dysfunction: a conservative target in metabolic disorders. – Inflammation Research 67(5): 391-405.
[17] Kabeerdass, N., Krishnamoorthy, S., Anbazhagan, M., Srinivasan, R., Nachimuthu, S., Rajendran, M., Mathanmohun, M. (2021a): Screening, detection and antimicrobial susceptibility of multi-drug resistant pathogens from the clinical specimens. – Materials Today: Proceedings 47: 461-467. https://doi.org/10.1016/j.matpr.2021.05.018.
[18] Kabeerdass, N., Al Otaibi, A., Rajendran, M., Manikandan, A., Kashmery, H. A., Rahman, M. M., Madhu, P., Khan, A., Asiri, A. M., Mathanmohun, M. (2021b): *Bacillus*-mediated silver nanoparticle synthesis and its antagonistic activity against bacterial and fungal pathogens. – Antibiotics 10(11): 1334. https://doi.org/10.3390/antibiotics10111334.
[19] Khan, M. A., Ali, R., Parveen, R., Najmi, A. K., Ahmad, S. (2016): Pharmacological evidences for cytotoxic and antitumor properties of boswellic acids from Boswellia serrata. – J Ethnopharmacol. 191: 315-23.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2002_919929

[20] Kumar, D., Kumar, V., Jalwal, P. (2016): Boswellic acid-potential tumors suppressant terpenoid-photochemistry, extraction and isolation methods-a comprehensive review study. – J Pharmacogn Phytochem. 5: 231.
[21] Maghimaa, M., Alharbi, S. A. (2020): Green synthesis of silver nanoparticles from Curcuma longa L. and coating on the cotton fabrics for antimicrobial applications and wound healing activity. – Journal of Photochemistry and Photobiology B: Biology. 1; 204: 111806.
[22] Niphadkar, S. S., Rathod, V. K. (2017): Extraction of acetyl 11-keto-?-boswellic acids (AKBA) from Boswellia serrata using ultrasound. – Sep Sci Technol. 52: 997-1005.
[23] Niphadkar, S. S., Rathod, V. K. (2018): Optimization of ethanol modified supercritical fluid extraction (SFE) of acetyl 11 keto? boswellic acid (AKBA) from Boswellia serrata using box-Behnken experimental design. – Biocatal Agric Biotechnol. 13: 304-10.
[24] Ohemu, T. L., Agunu, A., Chollom, S. C., Okwori, V. A., Dalen, D. G., Olotu, P. N. (2018): Preliminary phytochemical screening and antiviral potential of methanol stem bark extract of Enantia chlorantha Oliver (Annonaceae) and Boswellia dalzielii Hutch (Burseraceae) against Newcastle disease in Ovo. – Eur J Med Plants. 25: 1-8.
[25] Patil, S. S., Rathod, V. K. (2020): Synergistic effect of ultrasound and three phase partitioning for the extraction of curcuminoids from Curcuma longa and its bioactivity profile. – Process Biochem. 93: 85-93.
[26] Perleberg, C., Kind, A., Schnieke, A. (2018): Genetically engineered pigs as models for human disease. – Disease Models & Mechanisms 1: 11(1).
[27] Schmiech, M., Lang, S. J., Ulrich, J., Werner, K., Rashan, L. J., Syrovets, T. (2019): Comparative investigation of frankincense nutraceuticals: correlation of boswellic and lupeolic acid contents with cytokine release inhibition and toxicity against triple-negative breast cancer cells. – Nutrients 11: 2341.
[28] Sharma, N., Bhardwaj, V., Singh, S., Ali, S. A., Gupta, D. K., Paul, S. (2016): Simultaneous quantification of triterpenoic acids by high performance liquid chromatography method in the extracts of gum resin of Boswellia serrata obtained by different extraction techniques. – Chem Cent J. 10:49.
[29] Siemoneit, U., Tausch, L., Poeckel, D., Paul, M., Northoff, H., Koeberle, A., Jauch, J., Werz, O. (2017): Defined structure-activity relationships of boswellic acids determine modulation of Ca2+ mobilization and aggregation of human platelets by Boswellia serrata extracts. – Planta Medica 83(12/13): 1020-7.
[30] Sun, X., Veeraraghavan, V. P., Surapaneni, K. M., Hussain, S., Mathanmohun, M., Alharbi, S. A., Aladresi, A. A., Chinnathambi, A. (2021): Eugenol–piperine loaded polyhydroxy butyrate/polyethylene glycol nanocomposite-induced apoptosis and cell death in nasopharyngeal cancer (C666-1) cells through the inhibition of the PI3K/AKT/mTOR signaling pathway. – Journal of Biochemical and Molecular Toxicology 35(4): e22700.
[31] Taghizadeh, M., Maghaminejad, F., Aghajani, M., Rahmani, M. (2018): The effect of tablet containing Boswellia serrata and Melissa officinalis extract on older adults' memory: a randomized controlled trial. – Arch Gerontol Geriatr. 75: 146-50.
[32] Vahabi, S., Hakemi-Vala, M., Gholami, S. (2019): In vitro antibacterial effect of hydroalcoholic extract of Lawsonia inermis, Malva sylvestris, and Boswellia serrata on Aggregatibacter actinomycetemcomitans. – Adv Biomed Res. 8: 22.
[33] Vakayil, R., Kabeerdass, N., Kuppusamy, A., Mathanmohun, M. (2019): Phytochemical screening and antibacterial properties of Punica granatum extracts against gastrointestinal infection. An in-vitro study. – Uttar Pradesh Journal of Zoology 26: 25-32.
[34] Vakayil, R., Krishnamoorthy, S., Kumar, G. S., Ramasamy, N. S., Mathanmohun, M. (2020): Screening and identification of multi-drug resistance nosocomial infection, isolates from clinical specimen: a cross-sectional study. – Plant Archives 20(2): 7247-7251.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2002_919929

[35] Vakayil, R., Anbazhagan, M., Shanmugam, G., Ramasamy, S., Mathanmohun, M. (2021a): Molecular docking and in vitro analysis of phytoextracts from B. serrata for antibacterial activities. – Bioinformation 17(7): 667-672. DOI: 10.6026/97320630017667.

[36] Vakayil, R., Krishnamoorthy, S., Anbazhagan, M., Kumar, N. S., Mathanmohun, M. (2021b): Antibacterial potential of acorus calamus extracts against the multi-drug resistant nosocomial pathogens. – Uttar Pradesh Journal of Zoology. 24: 144-50.

[37] Vakayil, R., Muruganantham, S., Kabeerdass, N., Rajendran, M., Ramasamy, S., Alahmadi, T. A., Almoallim, H. S., Manikandan, V., Mathanmohun, M. (2021c): Acorus calamus-zinc oxide nanoparticle coated cotton fabrics shows antimicrobial and cytotoxic activities against skin cancer cells. – Process Biochemistry 111: 1-8. https://doi.org/10.1016/j.procbio.2021.08.024.

[38] Vakayil, R., Kabeerdass, N., Srinivasan, R., Shanmugam, G., Ramasamy, S., Mathanmohun, M. (2021d): Invitro and insilico studies on antibacterial potentials of phytochemical extracts. – Materials Today: Proceedings. 47: 453-460. https://doi.org/10.1016/j.matpr.2021.05.017.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2002_919929