RESEARCH ARTICLE
Open Access

Journal of Veterinary and Animal Sciences
ISSN (Print): 0971-0701, (Online): 2582-0605
https://doi.org/10.51966/jvas.2023.54.2.313.321

Detection of carbapenem resistant *Escherichia coli* in cattle and pigs

P. R. Sandeep [1*], R. Ambily [2], A. Irshad [3] and S. Joseph [4]
Department of Veterinary Microbiology
College of Veterinary and Animal Sciences, Mannuthy, Thrissur - 680 651
Kerala Veterinary and Animal Sciences University
Kerala, India

Sandeep, P.R., Ambily, R., Irshad.A and Joseph , S. 2023. Detection of carbapenem resistant *Escherichia coli* in cattle and pigs. *J. Vet. Anim. Sci.* **54**(2):313-321
DOI: https://doi.org/10.51966/jvas.2023.54.2.313-321

Received: 07.05.2022 *Accepted: 25.01.2023* *Published: 30.06.2023*

Abstract

The aim of this study was to detect the presence of carbapenem resistant Escherichia coli (E. coli) in cattle and pigs. Altogether, 100 samples were collected, 50 each from cattle and pigs including mastitic milk and faecal samples from healthy as well as diarrhoeic cattle and faecal samples and slaughter specimens from pigs. Bacteria were isolated from the samples and antibiotic sensitivity test was carried out. Eight isolates of E. coli were obtained from cattle and 15 isolates from pigs. The phenotypic resistance patterns against carbapenems (ertapenem, imipenem and meropenem) were analysed. In cattle, the four isolates from milk were observed to be sensitive to all the three carbapenems whereas, all the isolates obtained from faecal samples were resistant to all the three carbapenems. The four faecal and three intestinal isolates of E. coli from pigs showed sensitivity to all the three carbapenems. From a total of 10 faecal samples from pigs, four, three and one isolates showed resistance to ertapenem, imipenem and meropenem respectively. Among five isolates from intestine, one isolate showed resistance to ertapenem and imipenem and no isolate showed resistance to meropenem. Polymerase chain reaction (PCR) was carried out to find the presence of carbapenem resistance genes (bla_{SHV}, bla_{CTX}, bla_{TEM} and bla_{NDM}) in all the 23 isolates and the results revealed that seven (58.3 per cent) E. coli isolates carried bla_{SHV} gene and four (33.3 per cent) contained bla_{CTX} gene which encodes carbapenem resistant enzymes. Antibiogram using 14 commonly used antimicrobial agents revealed varied multidrug resistant patterns among the E. coli isolates.

Keywords: *Antibiogram, carbapenem resistance, Escherichia coli, multidrug resistance*

Indiscriminate and extensive use of antibiotics to treat bacterial infections in human beings and animals resulted in enormous antimicrobial pressure on the pathogens, leading to the development of antimicrobial resistance (AMR) (Shaikh *et al.*, 2015). Carbapenems are reserved

1. *M.Sc Scholar, Department of Veterinary Microbiology*
2,3. *Assistant Professor, Department of Veterinary Microbiology*
4. *Assistant Professor, Department of Livestock Products Technology*
**Corresponding author: sandeepraman19964u@gmail.com, Ph. 8281985960*

as the last resort in treatment of multi-drug resistant (MDR) infections in human beings. The bacterial infections associated with carbapenem resistant *Escherichia coli* (*E. coli*) strains are emerging as a major public health concern globally (Baran and Aksu, 2016). Production of β-lactamases or β-lactam hydrolysing agents is the most common mechanism of drug resistance; especially in *E. coli* against the β-lactam antibiotics like carbapenems. The spread of these carbapenem hydrolysing enzymes among enteric bacteria in hospital settings is of grave concern. Intestinal microflora of animals carry genes namely, bla_{CTX-M}, $bla_{TEM,}$ bla_{SHV} and integrons, which can act as a possible cause for drug resistance in humans and animals (Tshitshi *et al*., 2020; Ejaz *et al*., 2021). Various ESBL genes viz., bla_{SHV} (33.1 per cent), bla_{TEM} (22.5 per cent), bla_{CTX-M} (20.5 per cent) and bla_{OXA} (11.3 per cent) were detected in CRE. It was reported that 76.3 per cent of Gram negative bacteria isolated from dogs were positive for atleast one carbapenemase gene (Sankar *et al*., 2021).

Carbapenem resistant *Enterobacteriaceae* (CRE) isolates were detected in food-producing animals and companion animals (Taggar *et al.*, 2020). There are reports of identification of carbapenem resistant *E. coli* in cattle and pigs in different parts of the world. But studies carried out in India are rare and no studies have been carried out so far in Kerala. Hence, the present study was undertaken to detect the presence of carbapenem resistant *E. coli* in cattle and pigs. The study also aims at detecting the susceptibility of these isolates to other commonly used antibiotics.

Materials and methods

A total of 100 samples were obtained from 50 cattle and 50 pigs. These included mastitic milk samples [brought to the Department of Veterinary Microbiology, University Livestock Farms (ULF), Mannuthy and Department of Teaching Veterinary Clinical Complex (TVCC)] and faecal samples from cattle [from diarrhoeic and healthy cattle brought to TVCC department and ULF, Mannuthy] and faecal samples [from Centre for Pig Production and Research (CPRR), Mannuthy] and slaughter house specimens such as lungs, heart, liver and intestine [from Meat Technology Unit (MTU), Mannuthy and authorised slaughter houses in Thrissur district] from pigs during the period of 2017-2019.

The collected samples were immediately plated onto brain heart infusion agar (BHIA) under aseptic conditions and were incubated at 37°C for 24 h. The isolates were analysed for its colony morphology and subjected to Gram's staining. Those colonies, which revealed Gram negative rods were sub-cultured onto Mac Conkey Agar (MCA) and eosin methylene blue (EMB) agar and further subjected to various biochemical tests for the confirmation of the presence of *E. coli*. All the procedures are followed as per Quinn *et al*. (1994).

Antibiogram

Disc diffusion method (CLSI, 2018) was performed on Mueller Hinton Agar (MHA) plates to determine susceptibilities of different β-lactam and non-β-lactam antibiotics. Three carbapenem antibiotics (ertapenem, meropenem, imipenam) and 14 other commonly used antibiotics belonging to various classes with known concentration were analysed.

Polymerase Chain Reaction

The DNA was extracted from *E. coli* isolates using the Genomic DNA Purification Kit (Origin, Kerala) as per manufacturer's instructions. The concentration and purity of DNA were measured spectrophotometrically. The DNA extracted from *E. coli* isolates, showing phenotypic resistance to carbapenems, were subjected to PCR using primers targeting bla_{SHV}, bla_{CTX} (Bora *et al.,* 2014), bla_{TEM} and bla_{NDM} genes (Sankar *et al*., 2021).

A total volume of 12.5 µL reaction was prepared. The composition of single reaction mix for amplification was 6.25 µL of EmeraldAmp® GT PCR Master Mix, 1 µL each of forward and reverse primer (10 pm/µL), 3 µL of template DNA and 1.25 µL of nuclease free water. To each reaction tube, 9.5 µl of reaction mix and 3 µL of template DNA were added and subjected to initial denaturation (94°C for 5min) followed

by denaturation (94ºC for 1 min), annealing (56.9ºC, 63.2ºC, 65.6ºC, 66.7ºC for 1min for bla_{SHV}, bla_{CTX}, bla_{TEM}, bla_{NDM}, respectively), extension (72ºC for 2 min for bla_{SHV}, 72ºC for 1 min for bla_{CTX}, bla_{TEM}, bla_{NDM}, respectively), final extension (72ºC for 10 min for bla_{SHV}, bla_{CTX}, bla_{NDM}, 72ºC for 5 min for bla_{TEM}) and hold (4ºC for 10 min).

Results and discussion

The presence of *E. coli* was detected in eight samples from cattle (four isolates from mastitis milk and four isolates from diarrhoeic samples). Major pathogen associated with clinical mastitis in dairy cattle was reported to be *Staphylococcus aureus* followed by *E. coli* (Sumathi *et al*., 2008). In a study conducted by Ranjan *et al*. (2011) on aetiological agents associated with bovine mastitis in Jharkhand, *E. coli* could be isolated from only 8.95 per cent. Lakshmi and Jayavardhanan (2016) reported that 27 per cent of isolates from mastitic milk samples of cattle in organised farms in Kerala were *E. coli.* Fifteen *E. coli* isolates were obtained from pigs (10 isolates from faecal samples and 5 isolates from intestine). There were reports of isolation of *E. coli* from more than 50 per cent of faecal samples collected from pigs (Kagambega *et al.*, 2012; Lalzampuia *et al*., 2013). Individual animals shed *E. coli* in different concentrations due to several factors such as pathogen, host and environment and *E. coli* might not be isolated from all the faecal samples (Stein *et al*., 2017).

The carbapenem resistance pattern of *E. coli* isolates obtained from cattle and pigs were analysed against three carbapenem discs using disk diffusion method (CLSI, 2018) on MHA plates. Antibiotic susceptibility of the isolates to 14 commonly used antibiotic discs were also analysed. The varying degrees of resistance and susceptibility were observed (Table 1).

Table 1. Antibiotic sensitivity pattern of *E. coli* isolates from cattle and pigs

Species	Sample	*E. coli* isolate	Sensitivity to Antibiotics*														Sensitivity to Carbapenem**		
			CTX	CTR	AMX	CIS	CEC	EX	CIT	CN	GEN	PIT	TET	CPD	CAZ	COT	ETP	IPM	MRP
Cattle	Milk	C1	R	S	R	R	R	S	R	S	S	S	S	R	S	S	S	S	S
		C2	R	R	S	R	R	R	R	S	IN	R	S	R	S	S	S	S	S
		C3	R	S	S	R	R	R	R	R	S	R	R	R	S	S	S	S	S
		C4	R	S	R	R	R	R	S	S	R	R	R	R	S	S	S	S	S
	Faeces	C5	R	R	R	R	R	R	R	S	S	IN	R	R	S	S	R	R	R
		C6	R	S	S	R	R	R	R	IN	IN	IN	S	R	S	S	R	R	R
		C7	R	IN	S	R	R	S	R	S	S	IN	S	R	S	S	R	R	R
		C8	R	R	R	R	R	S	R	R	S	R	S	R	S	S	R	R	R
Pig	Faeces	P1	R	S	R	R	R	S	R	S	S	R	S	R	S	S	S	S	S
		P2	R	S	S	R	R	R	R	R	S	R	S	R	R	R	R	S	S
		P3	R	S	R	R	R	S	S	IN	IN	S	R	R	IN	S	R	S	R
		P4	R	R	IN	R	R	R	R	S	S	R	S	R	IN	S	S	S	S
		P5	R	S	S	R	R	S	R	S	S	R	S	R	IN	R	R	S	S
		P6	R	S	R	R	R	S	R	S	R	S	S	R	S	S	S	R	S
		P7	R	R	S	R	R	R	R	S	S	R	R	R	IN	R	S	S	S
		P8	R	S	S	R	R	IN	S	S	IN	S	S	R	S	S	S	R	S
		P9	R	S	R	R	R	S	S	S	S	R	S	R	S	S	S	S	S
		P10	R	S	S	R	R	R	R	R	S	R	S	R	R	R	R	R	S
	Intestine	P11	R	R	R	R	R	R	S	R	R	R	R	R	R	R	S	R	S
		P12	R	S	S	R	R	R	R	R	R	R	R	R	R	S	S	S	S
		P13	R	S	R	R	R	R	S	IN	R	S	R	R	R	S	R	S	S
		P14	R	IN	R	S	R	R	S	IN	S	R	R	R	R	R	S	S	S
		P15	R	R	R	S	R	S	R	R	R	IN	R	R	R	R	S	S	S

*Cefotaxime (CTX) - 30mcg, Ceftriaxone (CTR) - 30mcg, Amoxicillin (AMX) - 30mcg, Ceftriaxone/Sulbactam (CIS) - 30/15mcg, Cefotaxime/Clavulanic acid (CEC) - 30/10mcg, Enrofloxacin (EX) - 10mcg, Ceftriaxone/Tazobactam (CIT) - 30/10mcg, Cefalexin (CN) - 30mcg, Gentamicin (GEN) - 30mcg, Piperacillin/Tazobactam (PIT) - 100/10mcg, Tetracycline (TET) - 30mcg, Cefpodoxime (CPD) - 10mcg, Ceftazidime (CAZ) - 30mcg, Co-trimoxazole (COT) - 25mcg.

**Ertapenem (ETP) - 10mcg, Imipenem (IPM) - 10mcg, Meropenem (MRP) - 10mcg

All the *E. coli* isolates obtained from faecal samples collected from cattle were found to be resistant to all the three carbapenems (ertapenem, meropenem and imipenem) and all the four isolates found from milk were observed to be sensitive to all the three (Fig. 1). Similar results were made by Papp-Wallace *et al*. (2011) and Chika *et al.* (2017) who reported the presence of carbapenem resistant *E. coli* in cattle. However, in the present study, no difference in the resistance could be observed among the three carbapenems.

All the ten *E. coli* isolates from faecal sample from pigs showed different resistance patterns. Four isolates showed resistance to ertapenem and three were resistant to imipenem; only one isolate showed resistance to meropenem. Among five isolates obtained from intestine, only one isolate was resistant to ertapenem and imipenem where no isolate showed resistance to meropenem (Fig. 2).

The study revealed the presence of carbapenem resistant *E. coli* in cattle and pigs. Out of 23 *E. coli* isolates obtained from cattle and pigs, 12 isolates were found to be resistant to atleast one of the carbapenem antibiotics.

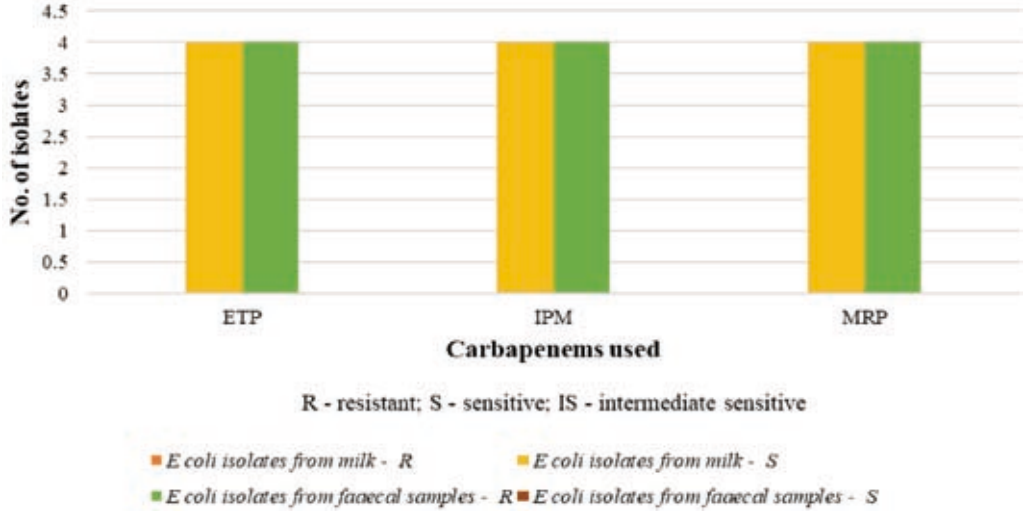

Fig. 1. Susceptibility of *E coli* isolates from cattle to carbapenems

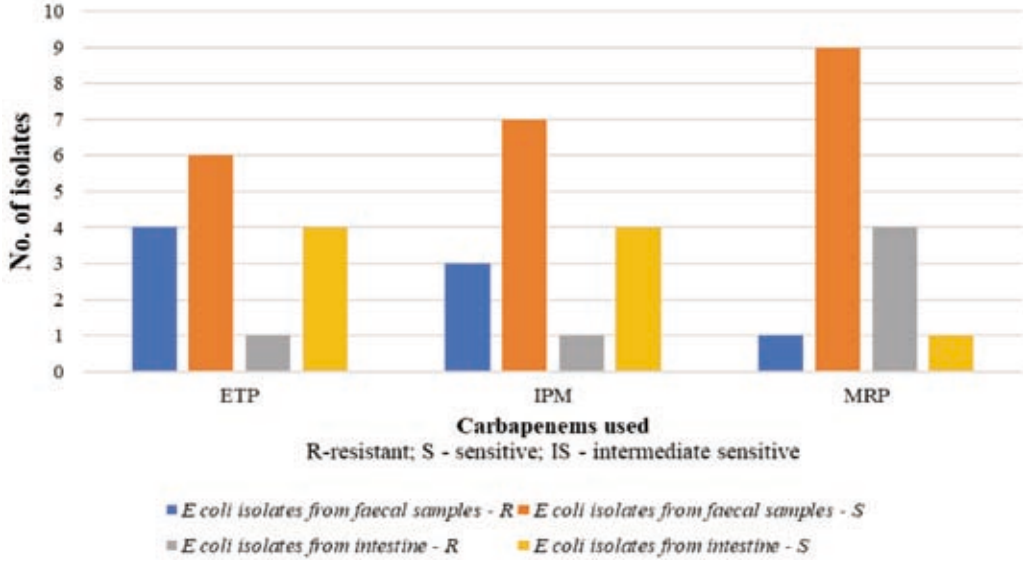

Fig. 2. Susceptibility of *E coli* isolates from pigs to carbapenems

These 12 isolates were subjected to PCR, targeting resistance genes such as bla_{SHV}, $bla_{CTX,}$ bla_{NDM} and bla_{TEM} using specific primers. Seven were positive for bla_{SHV}, four were positive for bla_{CTX} (Fig. 3 and 4) and all were negative for bla_{TEM} and bla_{NDM}.

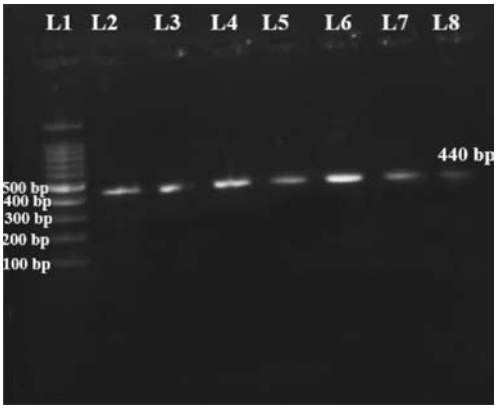

Fig. 3. Amplification of bla_{SHV} gene in *E. coli* L1 – 100bp Ladder L2 -L8 – Positive samples (Sample size- 440bp)

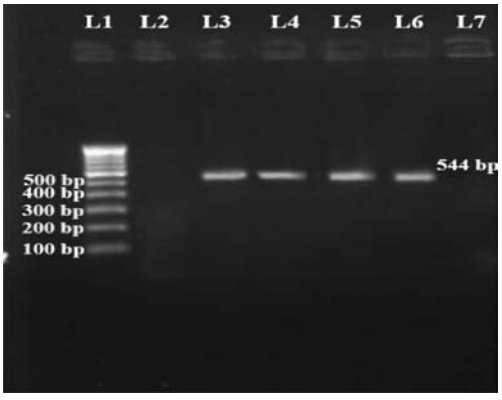

Fig. 4. Amplification of bla_{CTX} gene in *E. coli* L1 – 100bp Ladder L2 and L7 –Negative samples L3 – L6 –Positive samples (Sample size- 544bp)

Rita *et al*. (2021) confirmed the presence of bla_{CTX} gene in one *E. coli* isolate out of 27 isolates obtained from cattle. However, there are various reports on detection of bla_{SHV} and bla_{CTX} from *E coli* isolates from humans (Gondal *et al*., 2022). The transmission of these resistant genes from humans to animals and vice- versa pose a major threat to control of infection using these antimicrobials. However, further detailed surveillance of the resistant genes in personnels in contact with these animals is needed.

Carbapenem resistant *E. coli* were reported from pigs (Singh *et al*., 2017). In the present study, among the ten isolates from faecal samples from pigs, six (60 per cent) were resistant to at least one of the carbapenem drugs. This indicates that the personnel working in these pens with animals harbouring resistant microbes may have a chance to get horizontal transmission. From the five isolates from slaughter house specimens, two (40 per cent) were carbapenem resistant. None of the isolates were resistant to all the three as against Pruthvishree *et al*. (2016), who reported that 30 per cent of the carbapenem resistant *E. coli* were resistant to all the three carbapenems.

Antibiotic susceptibility testing using commonly used antibiotics revealed that all the eight isolates from cattle were found to be multidrug resistant. The four isolates from milk were resistant to cefotaxime, ceftriaxone/ sulbactam, cefotaxime/clavulanic acid and cefpodoxime. Among them, three were resistant to enrofloxacin (C2, C3 and C4), ceftriaxone/ tazobactam (CI, C2 and C3) and piperacillin/ tazobactam (C2, C3 and C4). Two isolates showed resistant to amoxicillin (CI and C4) and tetracycline (C3 and C4). Only one isolate showed resistance to ceftriaxone (C2), cefalexin (C3) and gentamicin (C4). All the four isolates were found to be sensitive to ceftazidime and co-trimoxazole (Fig. 5).

Antibiogram results showed that all the four isolates from faecal samples were resistant to cefotaxime, ceftriaxone/sulbactam, ceftriaxone/tazobactam, cefotaxime/clavulanic acid and cefpodoxime. Two isolates showed resistance to ceftriaxone (C5 and C8), amoxicillin (C5 and C8) and enrofloxacin (C5 and C6). Only one isolate showed resistance to piperacillin/tazobactam (C8), cefalexin (C8) and tetracycline (C5). All the four isolates were found to be sensitive to gentamicin, ceftazidime and co-trimoxazole (Fig. 5).

There are several reports on resistance of *E. coli* isolated from cattle to a variety of antimicrobials including penicillin, amoxicillin, tetracycline, oxytetracycline, methicillin, amoxyclav, cloxacillin, ceftriaxone, gentamicin and enrofloxacin (Chandrasekaran

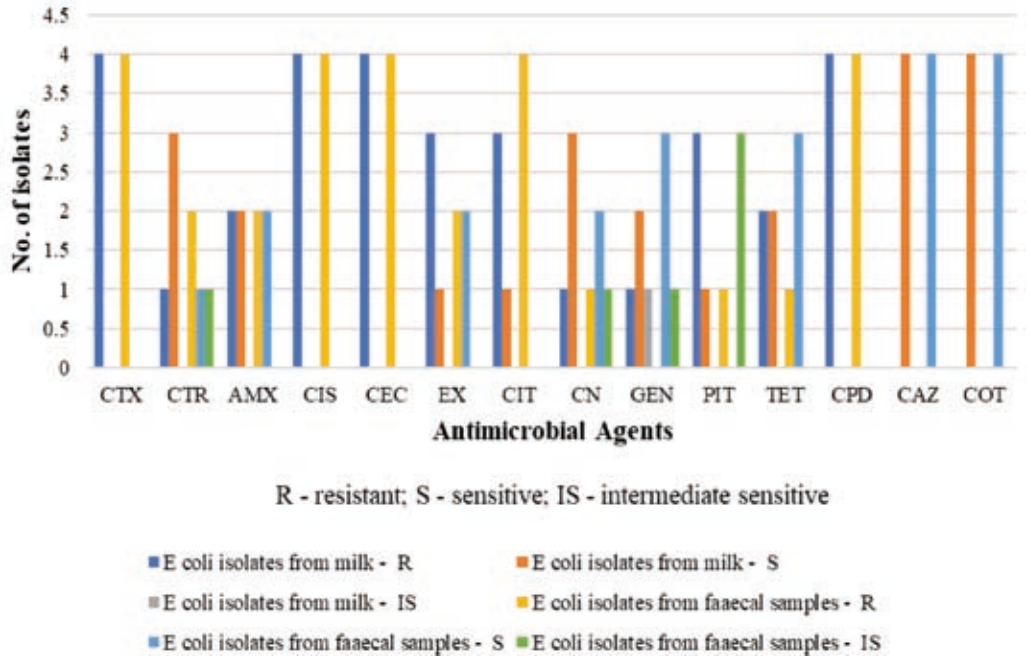

Fig. 5. Antimicrobial susceptibility pattern of *E. coli* isolates from cattle

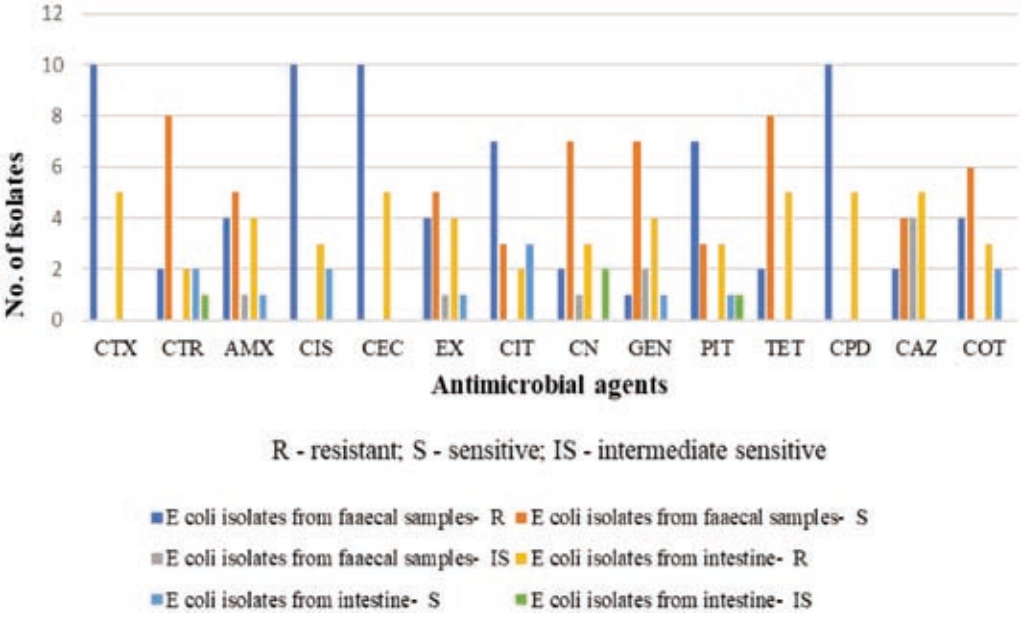

Fig. 6. Antibiotic susceptibility pattern of *E. coli* isolates from pigs

et al., 2014; Das *et al.,* 2017, Verma *et al.*, 2017; Revathi, 2018; Xavier *et al.,* 2020). However, Sumathi *et al.* (2008) observed that gentamicin was found to be the most effective drug. All the eight isolates were found to be sensitive to co-trimoxazole. Revathi (2018) also obtained similar result.

All the fifteen isolates from pigs were found to be multidrug resistant. Antibiogram results showed that the ten isolates from faecal samples were resistant to cefotaxime, ceftriaxone/sulbactam, cefotaxime/clavulanic acid and cefpodoxime. Seven of the isolates were resistant to ceftriaxone/tazobactam (P1, P2, P4, P5, P6, P7 and P10) and piperacillin/

tazobactam (P1, P2, P4, P5, P7, P9 and P10). Four isolates showed resistance to amoxicillin (P1, P3, P6 and P9), enrofloxacin (P2, P4, P7 and P10) and co-trimoxazole (P2, P5, P7 and P10). Two isolates were found to be resistant to ceftriaxone (P4 and P7), cefalexin (P2 and P10), tetracycline (P3 and P7) and ceftazidime (P2 and P10). Only one isolate was resistant to gentamicin (P6). All four isolates were found to be sensitive to ceftazidime and co-trimoxazole (Fig. 6).

Antibiogram results showed that all five isolates from the intestine of pig were resistant to cefotaxime, cefotaxime/clavulanic acid, tetracycline, cefpodoxime and ceftazidime. Four of the isolates were resistant to amoxicillin (P11, P13, P14 and P15), enrofloxacin (P11, P12, P13 and P14) and gentamicin (P11, P12, P13 and P15). Three isolates showed resistance to ceftriaxone (P11, P12 and P13), cefalexin (P11, P12 and P15), piperacillin/tazobactam (P11, P12 and P14) and co-trimoxazole (P11, P14 and P15). Two isolates were found to be resistant to ceftriaxone (P11 and P15) and ceftriaxone/tazobactam (P12 and P15) (Fig. 4).

E. coli in pigs were reported to be resistant to antibiotics like amoxicillin, oxytetracycline, trimethoprim, sulphonamide, streptomycin, cefixime, cefazolin, cephalexin, ceftriaxone, cefotaxime, enrofloxacin, ampicillin, chlortetracycline, erythromycin and lincomycin (van den Bogaard *et al*., 2000; Enne *et al*., 2007; Lalzampuia *et al.*, 2013). The present study revealed varying degrees of resistance and susceptibility of the isolates to the antimicrobial agents in the study.

Conclusion

The reports on detection of carbapenem resistant bacteria are rare in cattle and pigs. The occurrence of these bacteria in livestock has serious consequences and may affect therapeutic options in human medicine, since carbapenems are the last resort of antibiotic therapy. A key finding of this study was that 100 per cent of *E. coli* isolates recovered from faecal samples from cattle were resistant to all three carbapenems, ertapenem, meropenem and imipenem, which are not used in the livestock in Kerala. The high rate of resistance may reflect the increased clinical use of these antimicrobials among humans, which needs a thorough investigation. Hence, constant monitoring of carbapenem susceptibility among enteric bacteria of livestock is warranted. The bacteria were found to have various mechanisms conferring decreased sensitivity. The necessity for the study of antibiotic resistance and the associated genetic mechanisms is highly essential. Since a dependable substitute to carbapenems is not there, rationalisation of use of these antibiotics in both humans and animals is needed. The infection control measures should be meticulous whenever carbapenem resistance is detected and the active surveillance of carbapenemase-encoding genes are of the extreme importance. The tracing of the source of infection in livestock is important and all the steps should be taken to prevent the spreading of bacteria.

Acknowledgement

The authors thank Kerala Veterinary and Animal Sciences University, Pookode for providing the facilities for the conduct of the study

Conflict of interest

The authors declare that they have no conflict of interest.

References

Baran, I. and Aksu, N. 2016. Phenotypic and genotypic characteristics of carbapenem-resistant *Enterobacteriaceae* in a tertiary-level reference hospital in Turkey. *Ann. Clin. Microbiol. Antimicrob.* **15**: 20.

Bora, A. Hazarika, N.K., Shukla, S.K., Prasad, K.N., Sarma, J.B. and Ahmed, G. 2014. Prevalence of bla_{TEM}, bla_{SHV} and bla_{CTX-M} genes in clinical isolates of Escherichia coli and *Klebsiella pneumoniae* from Northeast India. *Indian J. Pathol. Microbiol*. **57**: 249-254.

Chandrasekaran, D., Venkatesan, P., Tirumurugaan, K.G., Nambi, A.P., Thirunavukkarasu, P.S., Kumanan, K., Vairamuthu, S. and Ramesh, S. 2014.

Pattern of antibiotic resistant mastitis in dairy cows. *Vet. Wld.* **7**: 389-394.

Chika, E., Charles, E., Ifeanyichukwu, I., Eucharia, O.C., Thaddeus, G., Angus, O.N., Malachy, U., Chika, E. and Ikegbunam, M.N. 2017. Detection of Metallo-β-lactamase (MBL) among Carbapenem-Resistant gram-negative bacteria from rectal swabs of cow and cloacae swabs of poultry birds. *Ann. Med. Hlth. Sci. Res.* **7**: 51-56.

Clinical and Laboratory Standards Institute 2018. Performance standards for antimicrobial susceptibility testing; 28th international supplement M100-S21. Wayne, PA: *CLSI*.

Das, A., Guha, C., Biswas, U., Jana, P.S., Chatterjee, A. and Samanta, I. 2017. Detection of emerging antibiotic resistance in bacteria isolated from subclinical mastitis in cattle in West Bengal. *Vet. Wld.* **10**: 517-520.

Ejaz, H., Younas, S., Abosalif, K.O.A., Junaid, K., Alzahrani, B., Alsrhani, A., Abdalla, A.E., Ullah, M.I., Qamar, M.U. and Hamam, S.S.M. 2021. Molecular analysis of bla_{SHV}, bla_{TEM} and bla_{CTX-M} in extended-spectrum β-lactamase producing *Enterobacteriaceae* recovered from fecal specimens of animals. *PLoS One*. **16**: 1-9.

Enne, V.I., Cassar, C., Sprigings, K., Woodward, M.J. and Bennett, P.M. 2007. A high prevalence of antimicrobial resistant *Escherichia coli* isolated from pigs and a low prevalence of antimicrobial resistant *E. Coli* from cattle and sheep in Great Britain at slaughter. *FEMS:Microbiol. Lett.* **278**: 193–199.

Gondal, A.J., Choudhry, N., Bukhari, H., Rizvi, Z. and Yasmin, N. 2022. Characterization of genomic diversity among carbapenem resistant *Escherichia coli* clinical isolates and antibacterial efficacy of silver nanoparticles from Pakistan. *Microorganisms.* **10**: 1-12

Kagambega, A., Martikainen, O., Siitonen, A. Traore, A.S., Barro, N. And Haukka, K. 2012. Prevalence of diarrheagenic Escherichia coli virulence genes in the feces of slaughtered cattle, chickens, and pigs in Burkina Faso. *Microbiol. Open.* **1**: 276–284.

Lakshmi, R. and Jayavardhanan, K.K. 2016. Isolation and identification of major causing bacteria from bovine mastitis. *Int. J. Appl. Pure Sci. Agric.* **2**: 45-48.

Lalzampuia, H., Dutta, T.K., Warjri, I. and Chandra, R. 2013. PCR-based detection of extended-spectrum b-lactamases ($bla_{CTX-M-1}$ and bla_{TEM}) in Escherichia coli, Salmonella spp. And Klebsiellapneumoniae isolated from pigs in North Eastern India (Mizoram). *Indian J. Microbiol.* **53**: 291–296.

Papp-Wallace, K.M., Endimiani, A., Taracila, M.A. and Bonomo, R.A. 2011. Mini review - Carbapenems: Past, Present and Future. *Antimicrob. Agents Chemother.* **55**: 4943-4960.

Pruthvishree, B.S., Vinodh Kumar, O.R., Sinha, D.K., Malik, Y.P.S., Dubal, Z.B., Desingu, P.A., Shivakumar, M., Krishnaswamy, N. and Singh, B.R. 2016. Spatial molecular epidemiology of carbapenem-resistant and New Delhi metallo beta-lactamase (bla_{NDM})-producing *Escherichia coli* in the piglets of organized farms in India. *J. Appl. Microbiol.* **122**: 1537-1546.

Quinn, P.J., Carter, M.E., Markey, B.K. and Carter, G.R. 1994. *Clinical Veterinary Microbiology.* Mosby Wolf, Spain. 648p.

Ranjan, R., Gupta, M.K. and Singh, K.K. 2011. Study of bovine mastitis in different climatic conditions in Jharkhand, India. *Vet. Wld*. **4**: 205-208.

Revathi, M. 2018. Virulence gene profiling of *Escherichia coli* from bovine mastitis and therapeutic management of coliform mastitis. *M. V. Sc. Thesis*, Kerala Veterinary and Animal Sciences University, Pookode, 43p.

Rita, O.L., Linda, A.O., Augustina, A.S., Matilda, A.A. and Kwasi, O.D. 2021. Antimicrobial resistance of Escherichia coli from broilers, pigs and cattle in the Greater Kumasi metropolis, Ghana. *Int. J. Microbiol.* **2021**: 02-04.

Sankar, S., Thresia, Bosewell, A. and Mini, M. 2021. Molecular detection of Carbapenem resistant gram negative bacterial isolates from dogs. *Indian J. Anim. Res.* **B-4297**: 1-5.

Shaikh, S., Fatima, J., Shakil, S., Rizvi, S.M.D. and Kamal, M.A. 2015. Antibiotic resistance and extended spectrum beta-lactamases: Types, epidemiology and treatment. *Saudi J. Biol. Sci.* **22**: 90-101.

Singh, B.R., Vinodh Kumar, O.R., Sinha, D.K., Bhardwaj, M., Vadhana, P., Singh, S.V., Saraf, A., Pruthvishree, B.S. and Tamta, S. 2017. List of Carbapenem (Meropenem or Imipenem or Ertapenem) Resistant Bacteria Isolated at Epidemiology Laboratory of Indian Veterinary Research Institute, Izatnagar, India from April 2011 to August 2017 from Different Animal Sources and their Environment and Phenotypic and Genotypic characterization of the Isolates for Different Carbapenemases. Researchgate. [online]. Available: *https://www.researchgate.net/publication/319872796 [September 2017]*.

Stein, R.A. and Katz, D.E. 2017. *Escherichia coli*, cattle and the propagation of disease. *FEMS*: *Microbiol. Lett*. **364**: 1-11.

Sumathi, B.R., Veeregowda, B.M. and Gomes, A.R. 2008. Prevalence and antibiogram profile of bacterial isolates from clinical bovine mastitis. *Vet. Wld*. **1**: 237-238.

Taggar, G., Rheman, M.A., Boerlin, P. and Diarra, M.S. 2020. Review: Molecular Epidemiology of Carbapenemases in Enterobacteriales from Humans, Animals, Food and the Environment. *Antibiotics*. **9**: 1-21.

Tshitshi, L., Manganyi, M.C., Montso, P.K., Mbewe, M. and Ateba, C.N. 2020. Extended Spectrum Beta-Lactamase-Resistant Determinants among Carbapenem-Resistant Enterobacteriaceae from Beef Cattle in the North West Province, South Africa: A Critical Assessment of Their Possible Public Health Implications. *Antibiotics*. **9**: 1-19.

van den Bogaard, A.E.J.M., London, N. and Stobberingh, E.E. 2000. Antimicrobial resistance in pig faecal samples from The Netherlands (five abattoirs) and Sweden. *J. Antimicrob. Chemother.* **45**: 663-671.

Verma, H., Rawat, S., Sharma, N., Jaiswal, V. and Singh, R. 2017. Prevalence, bacterial etiology and antibiotic susceptibility pattern of bovine mastitis in Meerut. *J. Ent. Zool. Stud.* **6**: 706-709.

Xavier, M., Janus, A., Deepa, P.M., Bipin, K.C., Habeeb, B.P. and Vijayakumar, K. 2020. Antibiogram of *Escherichia coli* isolates from faecal samples of neonatal calf diarrhoea in Wayanad district. *J. Vet. Anim. Sci.* **51**: 119-122.

■