

14. Pawar, N. J., Pawar, J. B., Supekar, A., Karmalkar, N. R., Kumar, S. and Erram, V. C., Deccan dykes as discrete and prospective aquifers in parts of Narmada-Tapi zone, Dhule District, Maharashtra. In *Indian Dykes* (eds Srivastava, R. K., Sivaji, Ch. and Chalapathi Rao, N. V.), Narosa Publishing House Pvt Ltd, New Delhi, 2009, pp. 189–198.
15. Ratnakumari, Y., Rai, S. N., Thiagarajan, S. and Dewashish Kumar, 2D Electrical resistivity imaging for delineation of deeper aquifers in a part of the Chandrabhaga river basin, Nagpur District, Maharashtra, India. *Curr. Sci.*, 2012, **102**(1), 61–69.
16. Rai, S. N., Thiagarajan, S., Ratnakumari, Y., Anand Rao, V. and Manglik, A., Delineation of aquifers in basaltic hard rock terrain using vertical electrical soundings data. *J. Earth Syst. Sci.*, 2013, **122**(1), 29–41.
17. Van Norstrand, R. and Cook, K. L., Interpretation of resistivity data, USCGS Professional Paper-499, US Govt. Printing Office, Washington, 1966.
18. Ritz, M., Parisot, J.-C., Diouf, S., Beauvais, A., Dione, F. and Niang, M., Electrical imaging of lateritic weathering mantles over granitic and metamorphic basement of eastern Senegal, West Africa. *J. Appl. Geophys.*, 1999, **41**, 335–344.
19. Dutta, S., Krishnamurthy, N. S., Arora, T., Rao, V. A., Ahmed, S. and Baltassat, J. M., Localization of water bearing fractured zones in a hard rock area using integrated geophysical techniques in Andhra Pradesh, India. *Hydrogeol. J.*, 2006, **14**, 760–766.
20. Krishnamurthy, N. S., Ananda Rao, V., Dewashish Kumar, Singh, K. K. K. and Shakeel Ahmed, Electrical resistivity imaging technique to delineate coal seam barrier thickness and demarcate water filled voids. *J. Geol. Soc. India*, 2009, **73**, 639–650.
21. Kumar, D., Rao, V. A., Nagaiah, E., Raju, P. K., Mallesh, D., Ahmeduddin, M. and Ahmed, S., Integrated geophysical study to decipher potential groundwater and zeolite-bearing zones in Deccan Traps. *Curr. Sci.*, 2010, **98**(6), 803–814.
22. Loke, M. H., Electrical imaging surveys for environmental and engineering studies – a practical guide to 2-D and 3-D surveys. Penang, Malaysia, 2011, <http://www.geoelectrical.com/coursenotes.zip>.
23. Dahlin, T. and Zhou, B., A numerical comparison of 2D resistivity imaging with ten electrode arrays. *Geophys. Prospect.*, 2004, **52**, 379–398.
24. Zarroca, M., Linares, R., Roqué, C., Rosell, J. and Gutiérrez, F., Integrated geophysical and morphostratigraphic approach to investigate a coseismic (?) translational slide responsible for the destruction of the Montclús village (Spanish Pyrenees). *Land-slides*, 2014; doi: 10.1007/s10346-013-0427-z.
25. Loke, M. H. and Barker, R. D., Rapid least-squares inversion of apparent resistivity pseudosections by a quasi-Newton method. *Geophys. Prospect.*, 1996, **44**, 131–152.
26. Sasaki, Y., Resolution of resistivity tomography inferred from numerical simulation. *Geophys. Prospect.*, 1992, **40**, 453–463.
27. Deolankar, S. B., The Deccan Basalt of Maharashtra, India – their potential as aquifers. *Groundwater*, 1980, **18**(5), 434–437.
28. Bobachev, A., Resistivity sounding interpretation, IPI2WIN: Version 3.0.1, a 7.01.03, 2003, Moscow State University.

ACKNOWLEDGEMENTS. We thank D. S. Ramesh, Director, IIG for permission to publish this work. We also thank the Principal and staff of Vijaya Gopal Gandhi Primary and Secondary Ashramshala, Utekhhol, for the logistic support during the field survey. We are grateful to Shri B. I. Panchal for drafting the figures.

Received 3 January 2015; revised accepted 4 January 2016

doi: 10.18520/cs/v111/i7/1246-1252

Multiplex-PCR assay for detection of some major virulence genes of *Salmonella enterica* serovars from diverse sources

Mridusmita Choudhury^{1,2}, Probodh Borah^{1,3,*}, Hridip Kumar Sarma², Luit Moni Barkalita³, Naba Kumar Deka¹, Isfaqu Hussain^{4,5} and Md. Iftikar Hussain^{1,2}

¹State Biotechnology Hub, Assam, College of Veterinary Science, Guwahati 781 022, India

²Department of Biotechnology, Gauhati University, Guwahati 781 014, India

³Department of Animal Biotechnology, and

⁴Department of Microbiology, College of Veterinary Science, Khanapara 781 022, India

⁵Faculty of Veterinary Microbiology and Immunology, Sher-e-kashmir University of Agricultural Sciences and Technology of Kashmir 190 006, India

The virulence of *Salmonella* depends on virulence factors encoded by specific genes. The present study describes the development of a simple and rapid multiplex PCR (m-PCR) assay for simultaneous detection of seven major virulence genes of *Salmonella* (*invA*, *invH*, *stn*, *sopB*, *sopE*, *sefC* and *pefA*). Presence of these genes was studied using 17 standard cultures and 76 field isolates from different sources. Seventeen non-*Salmonella* strains were also tested for specificity of the optimized PCR. A spiked control experiment was done to detect the sensitivity of m-PCR assay. The primer pairs were found to be specific for *Salmonella* only. The assay detected 250 pg of purified chromosomal DNA, or 12 cfu of *Salmonella* in crude lysates. All the field isolates and standard strains of *Salmonella* were found to carry *invA*, *invH*, *stn* and *sopB* genes, while variability was observed with respect to *sopE*, *sefC* and *pefA* genes. Thus this multiplex PCR assay provides a simple and rapid method for detection of major virulence factors in important clinical serovars of *Salmonella*.

Keywords: Multiplex PCR, *Salmonella*, spiking, virulence genes.

SALMONELLA, the Gram-negative bacillus of family Enterobacteriaceae, is widely distributed in nature and can cause diseases ranging from gastroenteritis to typhoid fever. More than 2500 serovars of *Salmonella* are known so far. *Salmonella enterica* subsp. *enterica* is one of the leading causes of zoonotic food-borne disease worldwide¹. *Salmonella* infections exhibit a complex pathogenesis in which numerous virulence genes are involved². These genes are clustered within *Salmonella* pathogenicity

*For correspondence. (e-mail: borahp@rediffmail.com)

islands (SPIs) and 21 such islands (SPI-1 to SPI-21) have been reported to date³. However, different serovars show variations in occurrence of these SPIs and individual genes⁴. Some genes such as *inv*, *sef*, etc. are involved in adhesion and invasion^{5,6}, while others are like *mgtC5* associated with survival in the host system, or in the actual manifestation of pathogenic processes, viz. *sop*, *stn*, *pip A, B, D*, etc.⁷⁻⁹. Serovars like *S. Typhimurium* also harbour self-transmissible virulence plasmids (pSLTs) carrying virulence genes such as the *spv* operon, involved in intramacrophage survival, and the plasmid-encoded fimbriae (*pef*) fimbrial operon^{10,11}. PCR assays have been developed for the detection of different gene-encoded virulence factors, viz. simplex PCR for *Salmonella* enterotoxin (*stn*)¹², *Salmonella enteritidis* fimbriae (*sef*) and plasmid encoded fimbriae (*pef*)¹³, and multiplex PCR (m-PCR) assays for a combination of a few such virulence factors¹⁴⁻¹⁶. Here, we report the development of a m-PCR for rapid and simultaneous detection of seven major virulence genes of *S. enterica*.

Seventeen standard cultures of *Salmonella* obtained from Microbial Type Culture Collection (MTCC), Chandigarh and National Institute of Cholera and Enteric Diseases (NICED), Kolkata, India were used for determination of sensitivity and specificity of the PCR assay (Table 1). A total of 17 non-*Salmonella* bacterial isolates mentioned elsewhere were used to check the specificity of PCR assay. Besides, 76 other *Salmonella* isolates obtained from faecal samples of different species of animals and birds (domestic and wild), including humans (children and adults with diarrhoea) were used to screen the virulence genes using PCR assay (Table 2).

Specific primers were designed for conserved regions of the gene sequences using on-line primer BLAST software of NCBI. Table 3 shows the GenBank accession numbers of the gene sequences used. Sequences of all the primers were evaluated using Primer-BLAST and BLASTn tools (<http://www.ncbi.nlm.nih.gov/tools/primer-blast/>) to identify any non-specific targets and ensure specificity of the PCR assay. The PCR products ranged from 185 to 942 bp in length. Proper care was taken to make sure that the primer pairs had similar annealing temperature and the resulting amplicons had a minimum 50 bp difference among them. The primers were synthesized by Integrated DNA Technologies (IDT), USA.

For standardization of m-PCR protocol, the bacterial DNA was isolated by a bacterial DNA isolation kit (Mo-Bio, USA), according to the instructions of the manufacturer. The purity and quantity of the extracted DNA were checked by Nanodrop spectrophotometer (ND 1000, Thermo Scientific, USA). Boiling lysis method of DNA extraction was followed for detection of various genes in different isolates of *Salmonella*¹⁷. DNA from the non-*Salmonella* isolates was also extracted by the same method. Briefly, all the bacterial cultures other than *Clostridium* species were grown aerobically in Luria Bertani

(LB) broth overnight at 37°C, while the clostridial cultures were grown in brain heart infusion (BHI) broth at 37°C for 24–48 h in an anaerobic jar. Next, 1 ml each of the above cultures was pelleted down by centrifugation at 15,322 g (relative centrifugal force) for 5 min. The pellet was resuspended in 100 µl of 1× Tris EDTA (TE) buffer (10 mM Tris-HCl, 1 mM EDTA, pH 8.0) and transferred to a micro-centrifuge tube. Bacterial suspension was boiled in a water-bath for 10 min and then immediately kept in ice for 10 min. It was again centrifuged at 15,322 g (rcf) for 10 min and the supernatant containing genomic DNA was collected. Quantification and purity of the freshly extracted DNA were checked with the help of Nanodrop-1000 Spectrophotometer and used immediately in the PCR reaction.

Initially, presence of virulence genes in the standard strains was confirmed by performing simplex PCR. m-PCR was optimized before the final experiment. Parameters optimized for m-PCR included primer concentration (0.2–0.5 µM), MgCl₂ concentration (2–3.5 mM), annealing temperature (50–60°C), annealing time (30–90 sec) and extension time (30–120 sec). Initially, each of the genes was amplified by simplex PCR using the same reaction conditions, i.e. 2 mM MgCl₂, 0.2 µM primer concentration for all genes, 50°C annealing temperature, 30 sec annealing time and 30 sec extension time. However, when the same conditions were used in m-PCR, no amplification was observed. Gradually all the parameters were adjusted step by step by applying them in different combinations. While amplification was observed for *pefA* and *sefC* genes with the combinations of 3.5 mM MgCl₂, 0.2 µM primer concentration for all primers, 56°C annealing temperature, 90 sec annealing time and 120 sec extension time, primer concentration for the remaining five genes (*invA*, *invH*, *stn*, *sopB* and *sopE*) had to be increased up to 0.4 µM for optimizing amplification (Table 1). Finally m-PCR parameters were established with 3.5 mM MgCl₂ concentration and a PCR cycle of initial denaturation at 94°C for 5 min, 35 cycles of 94°C for 30 sec, annealing at 56°C for 90 sec, extension at 72°C for 2 min and final extension at 72°C for 10 min. The m-PCR was carried out with a total reaction volume of 25 µl. The reaction mixture contained 12.5 µl of 2× PCR master-mix (Dream Taq PCR Master-Mix, Fermentas, USA), 1.5 µl of MgCl₂ (25 mM), 2.0 µl (40–60 ng) of template DNA and the final volume was made up with nuclease-free water. PCR amplification was performed in S1000 Thermal Cycler (Bio-Rad, USA). An aliquot (10 µl) from the PCR products of each sample was analysed by gel electrophoresis in 2% agarose gel containing ethidium bromide (0.5 µg ml⁻¹). The gel was visualized under a gel documentation system (GelDoc XR + system, Bio-Rad) and images were captured by Image Lab Software. Control reaction mixtures containing no template and negative control were also included in each of the sample runs.

Table 1. Virulence gene profiles of standard strains of *Salmonella*

Isolates	Strain no.	Virulence genes						
		<i>invA</i>	<i>invH</i>	<i>stn</i>	<i>sopB</i>	<i>sopE</i>	<i>sefC</i>	<i>pefA</i>
<i>S. Newport</i>	MTCC 3229	+	+	+	+	+	-	-
<i>S. Schwarzengrund</i>	MTCC 3230	+	+	+	+	-	-	-
<i>S. Typhimurium</i>	MTCC 98	+	+	+	+	+	-	+
<i>S. Typhimurium</i>	MTCC 3917	+	+	+	+	-	-	+
<i>S. Virchow</i>	MTCC 1166	+	+	+	+	+	-	-
<i>S. Abony</i>	NCTC 6017	+	+	+	+	+	-	-
<i>S. Choleraesius</i>	ATCC 10708	+	+	+	+	+	+	-
<i>S. Enteritidis</i>	IDH 5073	+	+	+	+	+	+	-
<i>S. Idikan</i>	NICED 503984	+	+	+	+	+	+	+
<i>S. Infantis</i>	NICED 505330	+	+	+	+	+	-	-
<i>S. Paratyphi A</i>	NICED C6915	+	+	+	+	+	-	-
<i>S. Paratyphi B</i>	NICED NK3727	+	+	+	+	+	-	-
<i>S. Poona</i>	NCTC 4840	+	+	+	+	+	-	-
<i>S. Typhi</i>	NICED C6953	+	+	+	+	+	+	-
<i>S. Vellore</i>	ATCC 15611	+	+	+	+	+	-	-
<i>S. Viridi</i>	IDH 377	+	+	+	+	+	-	-
<i>S. Worthington</i>	IDH 3642	+	+	+	+	+	-	-

Table 2. Virulence gene profiles of field isolates of *Salmonella*

Isolates	Source	No. of isolates	Virulence genes						
			<i>invA</i>	<i>invH</i>	<i>stn</i>	<i>sopB</i>	<i>sopE</i>	<i>sefC</i>	<i>pefA</i>
<i>S. Dublin</i>	Cattle	5	+	+	+	+	-	-	-
<i>S. Enteritidis</i>	Poultry	6	+	+	+	+	+	+	+
<i>S. Enteritidis</i>	Wild bird	6	+	+	+	+	+	+	+
<i>S. Enteritidis</i>	Human	3	+	+	+	+	+	+	+
<i>S. Gallinarum</i>	Wild bird	2	+	+	+	+	+	-	-
<i>S. Gallinarum</i>	Poultry	2	+	+	+	+	+	-	-
<i>S. Kentucky</i>	Tiger	2	+	+	+	+	-	-	-
<i>S. Litchfield</i>	Poultry	2	+	+	+	+	+	-	-
<i>S. Newport</i>	Poultry	3	+	+	+	+	+	-	-
<i>S. Newport</i>	Cattle	2	+	+	+	+	+	-	-
<i>S. Newport</i>	Human	2	+	+	+	+	-	-	-
<i>S. Typhi</i>	Human	2	+	+	+	+	-	+	-
<i>S. Weltevreden</i>	Poultry	7	+	+	+	+	-	-	-
<i>S. Weltevreden</i>	Wild bird	7	+	+	+	+	-	-	-
<i>S. Weltevreden</i>	Pig	7	+	+	+	+	-	-	-
<i>S. Weltevreden</i>	Kako snake	2	+	+	+	+	-	-	-
<i>S. Choleraesius</i>	Pig	6	+	+	+	+	+	+	-
<i>S. Typhimurium</i>	Pig	7	+	+	+	+	+	-	+
<i>S. Typhimurium</i>	Human	3	+	+	+	+	+	-	+

Sensitivity of the m-PCR assay was tested using *S. enterica* serovar enteritidis (IDH 5073) and Typhimurium (MTCC 98) strains to evaluate the minimal quantity of genomic DNA as well as cells required for their detection. To determine sensitivity, purified genomic DNA extracted using DNA isolation kit was serially diluted tenfold with sterile double-distilled water and amplified by PCR. To determine minimal cells required, overnight cultures of both strains were serially diluted tenfold up to 10⁻¹⁰ and viable counts were determined by plating 100 µl of each dilution of the bacterial culture on Brilliant Green Agar (BGA) plates and then incubated at

37°C for 18 h. The counts were expressed as cfu ml⁻¹. Finally, genomic DNA was isolated from 1 ml of the diluted cultures and amplified again. The number of cells/reaction of m-PCR or number of cells ml⁻¹ of culture required for detection by m-PCR was counted from the amount of template (2.0 µl) added in the m-PCR reaction. A panel of 17 non-*Salmonella* strains, viz. *Bacillus subtilis*, *Clostridium difficile*, *Clostridium perfringens*, *Escherichia coli* (n = 6), *Klebsiella pneumoniae*, *Pasteurella multocida*, *Proteus mirabilis*, *Pseudomonas aeruginosa*, *Shigella dysentery*, *Staphylococcus aureus*, *Streptococcus mutans* and *Pneumococcus pneumoniae*,

Table 3. Details of the primers used in the present study

Target gene	Primer sequence (5'-3')	Primer concentration (μ M)	Product size (bp)	Accession no.
<i>invA</i>	FP-ACCACGCTCTTTCGTCTGG RP-GAACTGACTACGTAGACGCTC	0.2	942	AE006468.1
<i>invH</i>	FP-TATAGCTGTCTTCTGTCTT RP-ATGTATTGTGGATGTTCTCG	0.2	305	AE006468.1
<i>stn</i>	FP-ATTGAGCGCTTTAATCTCCT RP-GCTGTTGAATCTGTACCTGA	0.2	543	AE006468.1
<i>sopB</i>	FP-AGCATCTCTAAACGCTACTG RP-GCTTCTATCACTCAGCTTCA	0.2	470	AE006468.1
<i>sopE</i>	FP-GGTAGGGCAGTATTAACCAG RP-TTTATCTCCCTAGGTAGCCC	0.2	254	AE014613.1
<i>pefA</i>	FP-GCCAAAGTACTGGTTGAAAG RP-TATTTGTAAGCCACTGCGAA	0.4	185	AE006471.1
<i>sefC</i>	FP-GGCAGGTCCAAAACATATACA RP-GCGATAACGAAACACCATT	0.4	609	AE014613.1

FP, Forward primer; RP, Reverse primer.

were tested for specificity using the optimized m-PCR conditions as mentioned above. The procedure was repeated twice to ensure reproducibility.

Spiking of stool sample was performed according to Pathmanathan *et al.*¹⁸ with some modifications. Briefly, 1 g of stool sample from a healthy individual was mixed with 10 ml of BHI broth. Then a known number of *Salmonella* Typhimurium cells was mixed with the faecal suspension to obtain a final concentration of 1, 10, 100, 1000 and 10,000 cfu ml⁻¹ and incubated for 10 h. The inoculated samples were harvested after 0, 5 and 10 h and PCR was performed using extracted DNA from the cultures. The sensitivity of PCR is defined as the lowest concentration of *Salmonella* Typhimurium (in cfu ml⁻¹ or cfu PCR⁻¹) that gives positive results. Faecal suspension without spiking was included in every PCR run as negative control to rule out false positives.

Two hundred and ninety-five diarrhoeic faecal samples/intestinal contents from poultry ($n = 52$), pig ($n = 60$) and humans ($n = 43$), faecal samples of domestic (cattle = 60), zoo animals (*Gekko gekko* = 10, *Panthera tigris* = 10) and wild birds ($n = 60$) were collected from various sources. All the faecal samples/intestinal contents were examined for the presence of *Salmonella* following standard enrichment and isolation procedures and also by m-PCR method. For this, 1 g of sample was inoculated in 10 ml of buffered peptone water and incubated at 37°C for 24 h. About 1 ml of pre-enriched culture was transferred to 9 ml of tetrathionate broth (Himedia, India) and incubated at 37°C for 24 h. Subsequently, a loopful of broth was streaked on the surface of BGA and xylose lysine deoxycholate (XLD) agar (Himedia) and incubated at 37°C for 24 h. Suspected colonies were further purified on MacConkey's lactose agar and biochemical tests were

carried out by conventional methods¹⁹. The isolates were also serotyped at NICED, Kolkata. Genomic DNA (2 μ l) prepared from 1 ml enrichment broth (5 h in buffered peptone water) by simple boiling method was used in m-PCR. The isolates were tested further by m-PCR for different virulent genes.

S. enterica subspecies *enterica* was detected in 76 (28.75%) out of 295 collected samples and ten serotypes were isolated, namely *S. Typhi*, *S. Typhimurium*, *S. Newport*, *S. Dublin*, *S. Enteritidis*, *S. Gallinarum*, *S. Sit-chfield*, *S. Weltevreden*, *S. Choleraesuis* and *S. Kentucky*. In humans 10 (23.25%) out of 43, in pig 20 (33.33%) out of 60, in cattle 7 (11.66%) out of 60, in poultry 20 (38.46%) out of 52, in wild bird 15 (25%) out of 60, in tiger 2 (20%) out of 10, and in gecko 2 (20%) out of 10 samples showed the presence of *S. enterica*. All the standard strains as well as 76 field isolates of *Salmonella* were found to be positive for *invA*, *invH*, *stn* and *sopB* genes, while there was variable presence of *sopE* (55.27%), *sefC* (30.26%) and *pefA* (32.90%) genes in the field isolates and 88.24%, 23.53% and 17.65% respectively, in the standard strains (Tables 2 and 3). All the *Salmonella* isolates yielded 942, 305, 470 and 543 bp amplicons for *invA*, *invH*, *sopB* and *stn* genes respectively, while the amplicon sizes for *sopE*, *sefC* and *pefA* were 254, 609 and 85 bp respectively (Figure 1). Overall, the results indicate high specificity of m-PCR, as it detected the presence of virulence genes in all the standard strains and field isolates of *Salmonella*. The m-PCR assay could detect approximately 250 pg of purified chromosomal DNA, or 12 cfu (5.9×10^3 cfu ml⁻¹) *Salmonella* cells in crude lysate. In the spiked control experiment, m-PCR could detect *Salmonella* Typhimurium at 0 h in the spiked sample containing 10^4 cfu ml⁻¹ (20 cfu PCR⁻¹ reaction in

RESEARCH COMMUNICATIONS

2 µl template). However, all the spiked samples containing 10 and 1000 cfu ml⁻¹ were found to be positive by m-PCR after 5 and 10 h of pre-enrichment. Three out of the five spiked samples containing one cfu ml⁻¹ were found to be positive after 5 and 10 h of incubation. No amplicons of corresponding sizes were detected in case of non-*Salmonella* strains, indicating the specificity of the assay. Repeated PCR amplifications gave similar reproducible results.

The *invA* gene of *Salmonella* contains sequences unique to this genus and has been proved to be a suitable PCR target with potential diagnostic application¹⁸. This gene is recognized as an international standard for detection of *Salmonella* genus¹⁹. The *invH* gene was detected in all the *Salmonella* isolates irrespective of serovars by PCR²⁰. However, it was not detected in many of the isolates tested by microarray analysis. The *stn* gene has been proposed as a putative virulence factor and causative

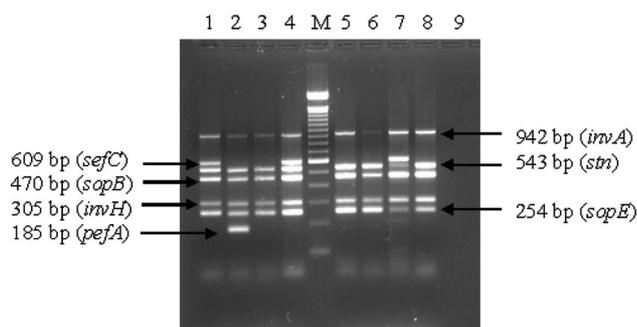


Figure 1. Detection of virulence genes of *Salmonella* by multiplex-PCR (m-PCR). Lane M, 100 bp ladder; lane 1, *S. Typhi*; lane 2, *S. Typhimurium*; lane 3, *S. Virchow*; lane 4, *S. Choleraesuis*; lane 5, *S. Paratyphi A*; lane 6, *S. Paratyphi B*; lane 7, *S. Enteritidis*; lane 8, *S. Newport*; lane 9, Negative control.

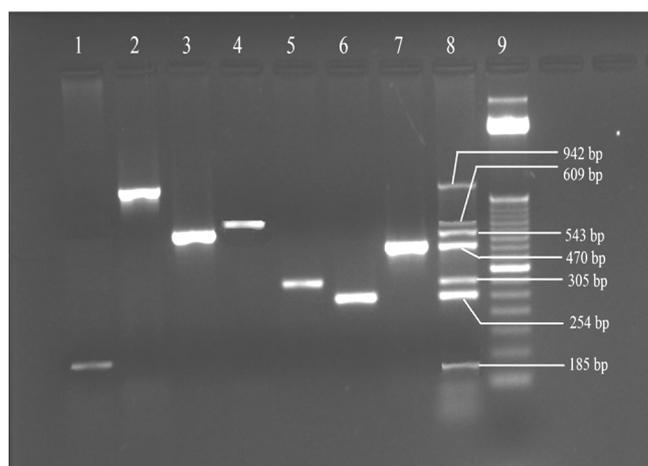


Figure 2. Detection of seven genes in simplex PCR and m-PCR. Lane 1, *pefA* (185 bp); lane 2, *invA* (942 bp); lane 3, *stn* (543 bp); lane 4, *sefC* (609 bp); lane 5, *invH* (305 bp); lane 6, *sopE* (254 bp); lane 7, *sopB* (470 bp); lane 8, m-PCR of *S. Idikan*; lane 9, 50 bp ladder (Invitrogen).

agent of diarrhoea⁶. Detection of *stn* gene was reported in all the strains of *S. enterica*, but not in *S. Bongori*⁷.

Salmonella outer proteins (Sop) are the effector molecules of type-III secretion system (TTSS) which are involved in the early stage of *Salmonella* infection. These proteins are encoded by *sop* genes and several polymorphisms of these genes have been identified (*sopA-sopE*)⁸. Among the different types of Sop proteins (SopB, a 60 kDa protein), initially identified in the culture filtrate of *S. enterica* serovar Dublin, was found to be associated with *Salmonella*-induced diarrhoea and gastroenteritis⁷.

We detected *sopB* gene in all the serovars of *Salmonella* tested, irrespective of host species and place of origin. Our finding is similar to that of Rahman²², who detected *sopB* gene by PCR in all tested serovars of *Salmonella* from humans and animals. On the contrary, the *sopE* gene was found to be present in 15 of the 17 standard *Salmonella* strains and was absent in *S. Schwarzengrund* and *S. Typhimurium*. Similarly, it was detected in the field isolates of *S. Enteritidis*, *S. Gallinarum*, *S. Litchfield* and *S. Newport*. However, variation was observed in the same serovars (e.g. *S. Newport* and *S. Typhimurium*). Our findings are similar to those of Rahman *et al.*^{23,24}, who also detected *sopE* gene in *S. Enteritidis*, *S. Gallinarum* and *S. Virchow* isolates by PCR. The product of this gene is shown to play a role in *Salmonella* virulence; however, its absence from multiple invasive *Salmonella* isolates suggests that it is unnecessary for invasive manifestation in humans²⁵. In the present study, presence of *pefA* gene was also evaluated, which encodes for the major portion of the *pef* operon. The *pefA* gene was detected in 3 of the 17 standard *Salmonella* strains, and 25 of the 76 *Salmonella* isolates belonging to serovars *S. Enteritidis*, *S. Typhimurium* and *S. Idikan* among field isolates. Our findings are in agreement with those of Murugkar *et al.*²⁶, who detected the *pef* gene in *S. Enteritidis*, *S. Paratyphi B* and *S. Typhimurium* isolates from humans, animals and birds. They found it to be absent in *S. Bareilly* isolates. However, they recorded variation among isolates of the same serovar. We also could not detect this gene in the standard strains of *S. Enteritidis* and *S. Paratyphi B* tested. This inter-serovar variation in the presence of *pef* gene has also been recorded previously¹³. However, few researchers could not detect *pef* gene in *S. Typhi*, *S. Paratyphi A* and *S. Typhimurium*²⁷. *Salmonella* Enteritidis fimbriae 14 (SEF 14) is one of the major fimbriae of *Salmonella*, encoded by fimbrial operons *sefA*, *sefB*, *sefC* and *sefD*⁵. *SefC* forms the largest component of the fimbriae and its presence indicates SEF adhesion. The *sefC* gene was found to be present only in *S. Enteritidis*, *S. Typhi*, *S. Choleraesuis* and *S. Idikan* serovars of both field isolates and standard strains of *Salmonella*. The present findings are more or less similar to those of Rahman *et al.*¹³, who showed that except for strains of *S. Enteritidis* and *S. Gallinarum*, none of the other serovars, viz. *S. Typhimurium*, *S. Newport*, *S. Kentucky*, *S. Weltevreden*

and *S. Indiana* harboured this gene. Similarly, researchers also recorded this gene in field isolates of *S. Enteritidis* of human and animal origin only²⁶. In our study, *sefC* gene was found to be absent in *S. Typhimurium*, *S. Newport*, *S. Kentucky*, *S. Weltevreden*, *S. Choleraesuis*, *S. Virchow*, *S. Schwarzengrund*, *S. Paratyphi B*, *S. Infantis*, *S. Abony*, *S. Poona*, *S. Vellore*, *S. Viridi* and *S. Worthington*. The *sefA* gene was detected in *S. Dublin*, in addition to *S. Enteritidis*²⁷.

The reaction condition for m-PCR assay was optimized to ensure that all the target virulence gene sequences were satisfactorily amplified. The annealing temperature of 56°C was selected because at this temperature adequate resolution of all the amplified products could be seen without any non-specific bands. The primer concentration was optimized after standardizing individual simplex PCRs for the studied genes and showed similar annealing temperatures without any non-specific amplification. m-PCR also confirmed the virulence gene profile (Table 3) of the isolates without any non-specific bands (Figure 2). m-PCR had a reasonably high level of sensitivity in spiked human stool samples. m-PCR in the present study had a reasonably high level of sensitivity and was able to detect as low as 10 organisms per gram of stool sample following 5 h enrichment in buffered peptone water. Lim *et al.*²⁸ reported that the sensitivity of m-PCR was 500 ng DNA of *S. Enterica* serovar Typhimurium. Kapley *et al.*²⁹ reported higher sensitivity of the PCR reaction with 10² cells ml⁻¹ for amplification of *invA*, *lamB* and *ctxA* genes of *Salmonella* Typhi, *E. coli* and *Vibrio cholerae*. Our findings are similar to those of Pathmanathan *et al.*¹⁸, who found increased sensitivity of PCR for detection of *S. Typhimurium* in direct stool samples from 1200 cfu PCR⁻¹ to 120 cfu PCR⁻¹ and 1.2 cfu PCR⁻¹ after 4 and 6 h pre-enrichment of stool samples respectively. Further, the results showed that DNA templates from all the *Salmonella* isolates yielded 942, 305, 470 and 543 bp amplicons for *invA*, *invH*, *sopB* and *stn* genes respectively, while 254, 609 and 185 bp products (Figure 1) for *sopE*, *sefC* and *pefA* respectively, were produced by strains which harboured these genes. No amplicons of corresponding sizes were detected in case of non-*Salmonella* strains, indicating the specificity of the assay. Therefore, this assay demonstrates 100% specificity since all the desired amplicons were produced in *Salmonella* isolates, while no amplicon was produced from any of the non-*Salmonella* strains tested.

All the field isolates of corresponding serovars from the same source were found to have the same virulence gene profile in the m-PCR assay. The m-PCR assay developed in the present study was able to concurrently amplify more than one common as well as uncommon virulence locus in a single reaction. Since *invH*, *stn* and *sopB* genes were found in all the isolates, they can be used as alternative target genes for direct detection of *Salmonella* from biological sources. This assay provides

a rapid and reliable detection method for detection of *Salmonella* isolates with pathogenic potential and to compare their virulence gene profiles.

Both conventional PCR and m-PCR could detect presence of *Salmonella* Typhimurium in the spiked samples (faeces and bacterial growth). The inoculated samples enriched in tetrathionate broth and sub-cultured on BGA plates also yielded positive results in three of the five spiked samples containing 1 cfu ml⁻¹ after 5 and 10 h of incubation, whereas PCR results were positive for all concentrations of *Salmonella* Typhimurium (in cfu ml⁻¹ or cfu PCR⁻¹). Khan *et al.*³⁰ found *Salmonella*-positive results in food-spiked samples containing 1 cfu ml⁻¹ after 10 h of incubation, implying that the m-PCR assay developed is more sensitive for detection of the target organism than the conventional culture method.

Conflict of interest: Authors declare that there is no conflict of interest with anyone in respect of the present study.

1. Toboldt, A., Tietze, E., Helmuth, R., Junker, E., Fruth, A. and Malornya, B., Population structure of *Salmonella enterica* serovar 4, [5], 12: b: strains and likely sources of human infection. *Appl. Environ. Microbiol.*, 2013, **79**, 5121–5129.
2. Hensel, A., Evolution of pathogenicity islands of *Salmonella enterica*. *Indian J. Med. Microbiol.*, 2004, **294**, 95–102.
3. Wisner, A., Desin, T., White, A., Potter, A. and Köster, W., The *Salmonella* pathogenicity island-1 and-2 encoded type III secretion systems. In *Salmonella – A Diversified Superbug* (ed. Kumar, Y.), InTech, Croatia, 2012, pp. 469–494.
4. Sabbagh, S. C., Forest, C. G., Lepage, C., Leclerc, J. M. and Daigle, F., So similar, yet so different: uncovering distinctive features in the genomes of *Salmonella enterica* serovars Typhimurium and Typhi. *FEMS Microbiol. Lett.*, 2010, **305**, 1–13.
5. Galan, J. E., Ginocchio, C. and Costeas, P., Molecular and functional characterization of the *Salmonella* invasion gene *invA*: homology of InvA to members of a new protein family. *J. Bacteriol.*, 1998, **174**, 4338–4349.
6. Clouthier, S. C., Collinson, S. K. and Kay, W. W., Unique fimbriae-like structures encoded by *sefD* of the SEF 14 fimbrial gene cluster of *Salmonella* Enteritidis. *Mol. Microbiol.*, 1994, **12**, 893–901.
7. Chopra, A. K. *et al.*, Role of *Salmonella* enterotoxin in overall virulence of the organism. *Microb. Pathogenesis*, 1999, **27**, 155–171.
8. Wood, M. W., Jones, M. A., Watson, P. R., Hedges, S., Wallis, T. S. and Galyov, E. E., Identification of a pathogenicity island required for *Salmonella* enteropathogenicity. *Mol. Microbiol.*, 1998, **29**, 883–891.
9. Wallis, T. S. and Galyov, E. E., Molecular basis of *Salmonella* induced enteritis. *Mol. Microbiol.*, 2000, **36**, 997–1005.
10. Ahmer, B., Tran, M. and Heffron, F., The virulence plasmid of *Salmonella* Typhimurium is self-transmissible. *J. Bacteriol.*, 1999, **181**, 1364–1368.
11. Rotger, R. and Casadesus, J., The virulence plasmids of *Salmonella*. *Int. Microbiol.*, 1999, **2**, 177–184.
12. Prager, R., Fruth, A. and Tschape, H., *Salmonella* enterotoxin (*stn*) gene is prevalent among strains of *Salmonella enterica* but not among *Salmonella bongori* and other Enterobacteriaceae. *FEMS Immunol. Med. Microbiol.*, 1995, **12**, 47–50.

RESEARCH COMMUNICATIONS

13. Rahman, H., Prager, R. and Tschape, H., Occurrence of *sef* and *pef* genes among different serovars of *Salmonella*. *Indian. J. Med. Res.*, 2000, **111**, 40–42.
14. Alvarez, J., Sota, M., Vivanco, A. B., Perales, I., Cisterna, R., Rementeria, A. and Garaizar, J., Development of a multiplex PCR technique for detection and epidemiological typing of *Salmonella* in human clinical samples. *J. Clin. Microbiol.*, 2004, **42**, 1734–1738.
15. de Freitas, C. G. *et al.*, PCR multiplex for detection of *Salmonella* Enteritidis, Typhi and Typhimurium and occurrence in poultry meat. *Int. J. Food Microbiol.*, 2010, **139**, 15–22.
16. Saeki, E. K., Juliane, A. J., Bonfante, R. C., Elisa, Y., Hirooka, E. Y. and de Oliveira, T. C. R. M., Multiplex PCR (mPCR) for the detection of *Salmonella* spp. and the differentiation of the Typhimurium and Enteritidis serovars in chicken meat. *J. Food Saf.*, 2013, **33**, 25–29.
17. Theron, J., Morar, D., Preez, D. U., Brozel, M. V. S. and Venter, S. N., A sensitive seminested PCR method for the detection of *Shigella* in spiked environmental water samples. *Water. Res.*, 2001, **35**, 869–874.
18. Pathmanathan, S. G., Cardona-Castro, N., Sánchez-Jiménez, M. M., Correa-Ochoa, M. M., Puthucheary, S. D. and Thong, K. L., Simple and rapid detection of *Salmonella* strains by direct PCR amplification of the *hila* gene. *J. Med. Microbiol.*, 2003, **52**, 773–776.
19. Jamshidi, A., Bassami, M. R. and Afshari-Nic, S., Identification of *Salmonella* serovars Typhimurium by a multiplex PCR-based assay from poultry carcasses in Mashhad-Iran. *Int. J. Vet. Res.*, 2008, **3**, 43–48.
20. Malorny, B., Hoorfar, J., Bunge, C. and Helmuth, R., Multicenter validation of the analytical accuracy of *Salmonella* PCR: towards an international standard. *Appl. Environ. Microbiol.*, 2003, **69**, 290.
21. Zou, W. *et al.*, Microarray analysis of virulence gene profiles in *Salmonella* serovars from food/food animal environment. *J. Infect. Dev. Ctries.*, 2011, **5**, 94–105.
22. Rahman, H., Prevalence and phenotypic expression of *sopB* gene among clinical isolates of *Salmonella enterica*. *Indian. J. Med. Res.*, 2006, **123**, 83–88.
23. Rahman, H., Streckel, W., Prager, R. and Tschape, H., Prevalence of *sopE* gene & its phenotypic expression among different serovars of *Salmonella* isolated from man and animals. *Indian. J. Med. Res.*, 2004, **120**, 35–38.
24. Rahman, H., Hardth, W. D., Muruhkar, H. V. and Bhattacharyya, D. K., Occurrence of *sopE* gene and its phenotypic expression among different serovars of *Salmonella enterica* isolated from man and animals. *Indian. J. Exp. Biol.*, 2005, **43**, 631–634.
25. Suez, J. *et al.*, Virulence gene profiling and pathogenicity characterization of non-typhoidal *Salmonella* accounted for invasive disease in humans. *PLoS ONE*, 2013, **8**, e58449.
26. Murugkar, H. V., Rahman, H. and Dutta, P. K., Distribution of virulence genes in *Salmonella* serovars isolated from man and animals. *Indian J. Med. Res.*, 2003, **117**, 66–70.
27. Muthu, G. *et al.*, Detection of virulence genes from *Salmonella* species in Chennai, India. *CIB Tech. J. Microbiol.*, 2014, **3**, 11–14.
28. Lim, Y. H. *et al.*, Multiplex polymerase chain reaction assay for selective detection of *Salmonella enterica* serovar Typhimurium. *Jap. J. Infect. Dis.*, 2003, **56**, 151–155.
29. Kapley, A., Lampel, K. and Purohit, H. J., Thermocycling steps and optimization of multiplex PCR. *Biotechnol. Lett.*, 2000, **22**, 1913–1918.
30. Khan, A. B., Sahir, K. H., Ahmed, M. and Khan, S. I., Rapid detection of *Salmonella* in food samples by polymerase chain reaction after a 10 h preenrichment. *J. Food Safety*, 2014, **34**, 79–86.

ACKNOWLEDGEMENTS. We thank the Department of Biotechnology, New Delhi for funds and State Biotechnology Hub, College of Veterinary Science, Khanapara for providing laboratory facilities. We also thank Dr T. Ramamurthy (NICED, Kolkata) for providing a few standard cultures of *Salmonella*.

Received 10 April 2015; revised accepted 13 May 2016

doi: 10.18520/cs/v111/i7/1252-1258