

Review Article

Description of New Taxa of Prokaryotes: A Decadal Work in India

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The taxonomic description of novel taxa of prokaryotes from India in the (2006-2016) decade was reviewed. In all 332 new species descriptions according to “bacteriological code” are there from India since 2006. These descriptions are based on strains isolated from India and also from outside India. During this period, all the new taxa described belong to the domain Bacteria with no representation from the domain Archaea. The major habitats studied include soil, marine sediments, water samples from fresh and marine sources with specimens and insects also being explored. The species belonging to phyla Proteobacteria was majorly described. Universities are the major centres for research leading to new taxa descriptions and more and more groups are contributing to description of novel taxa of prokaryotes.

Keywords: Taxonomic Description; Prokaryotes; Bacteria; India; Research Institutions

Introduction

Prokaryotic new taxa description in India: 2006-2016

India is one of the mega biodiverse countries with four biodiversity hotspots and abounds in biodiversity. While the wealth of this diversity with respect to higher forms of life, viz., plants and animals is well explored and inventoried, such efforts in prokaryote diversity are insignificant only catching up now. This article reviews new taxa, descriptions of prokaryotes in the last decade based on work done in India. While most of the descriptions of novel prokaryote taxa in the last decade (2006-2016) pertain to samples from India, those of Dr. Shivaji’s group from Centre for Cellular and Molecular Biology (CCMB) also pertain to samples from the Antarctica, Arctic Ocean and stratosphere.

In general, Asia is contributing significantly to the description of novel taxa of prokaryotes. The position of India in global description is 7th having 332 new taxa descriptions in the decade 2006-2016 (Fig.

1). Among the Prokaryotes all the new taxa described in this decade belong to the domain Bacteria with no representation from the domain Archaea, though two species of Archaea were described earlier (Kadam *et al.*, 1994 and Savant *et al.*, 2002).

Habitats from which New Species are Described

Research work leading taxonomic description of new species was carried out based on strains isolated from Indian samples and also samples from the Antarctica (Gupta *et al.*, 2006; Shivaji *et al.*, 2015), arctic (Begum *et al.*, 2013; Srinivas *et al.*, 2013) and stratosphere (Shivaji *et al.*, 2006). Diverse habitats of India had been explored for discovery of novel taxa. Indian habitats studied ranges from Himalayan glaciers (Chaturvedi and Shivaji, 2006; Pindi *et al.*, 2009), cold deserts (Mayilraj *et al.*, 2006), hot deserts (Subhash *et al.*, 2014a; Divyasree *et al.*, 2015) to hot springs (Saha and Chakrabarti, 2006; Tripathi *et al.*, 2016), from pristine environments (Anil *et al.*, 2007; Jyothsna *et al.*, 2008) to highly polluted dumpsites (Anil *et al.*, 2008; Anil *et al.*, 2011; Verma *et al.*, 2015), effluent treatment plants (Kaur *et al.*, 2014;

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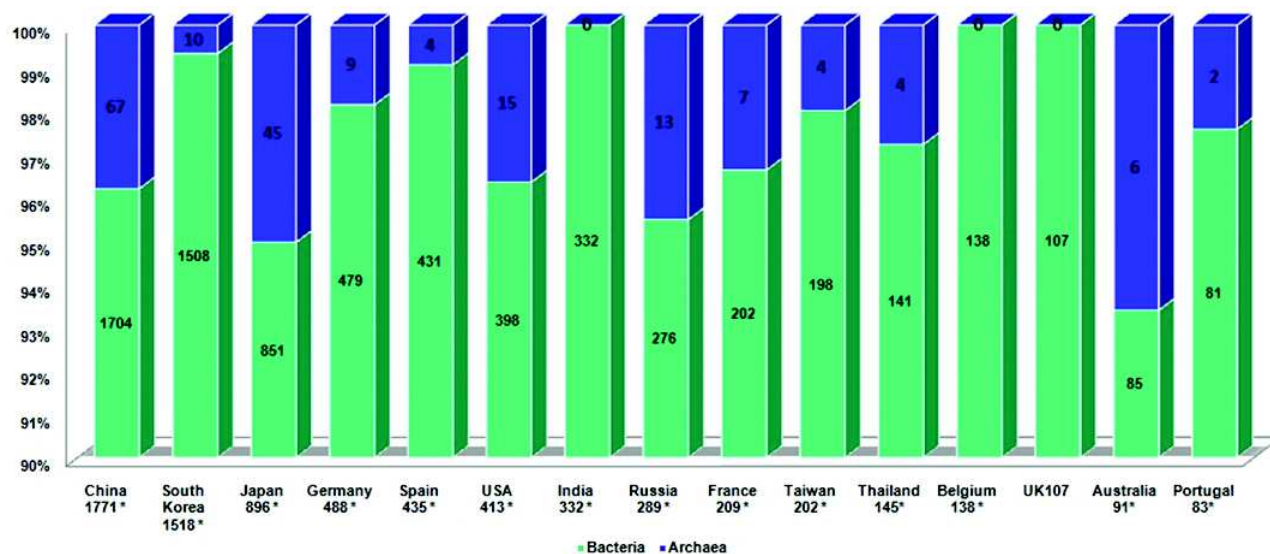


Fig. 1: Description of new species of Bacteria and Archaea from various countries during the decade 2006-2016; *- Total number of prokaryotes species published

Singh *et al.*, 2015a). Agricultural soils (Anil *et al.*, 2008; Lakshmi *et al.*, 2013; Jha *et al.*, 2015) also have been sources of new species of bacteria. It was interesting to see that contamination of pure cultures also yielded strains based on which new species were described (Subhash *et al.*, 2014b; Azmatunnisa *et al.*, 2015). Marine and estuarine waters (Nupur *et al.*, 2015; Rahul *et al.*, 2015; Divyasree *et al.*, 2016) and sediments (Shivani *et al.*, 2015; Ramprasad *et al.*, 2015), including salt pans (Subhash *et al.*, 2013; Divyasree *et al.*, 2016; Sharma *et al.*, 2016) form the major source of new species (Fig. 2) followed by soil.

Different Phyla and Genera of Bacteria to which New Species Described Belonged

New species descriptions from India are restricted to only 8 phyla (Fig. 3). In accordance with the findings globally that *Proteobacteria*, *Firmicutes*, *Bacteroidetes* and *Actinobacteria* are the most widely encountered phyla during culturing studies, species of bacteria described from India also belong to these phyla. Proteobacteria lead the list with 46 % of species described followed by *Actinobacteria* (19%), *Firmicutes* (19%), *Bacteroidetes* (13%), *Spirochaetes* (1%) and *Deinococcus Thermus* (1%) group. *Chlorobi* and *Thermotagae* have one new species described in each. Though new species of *Cyanobacteria* are also described including in

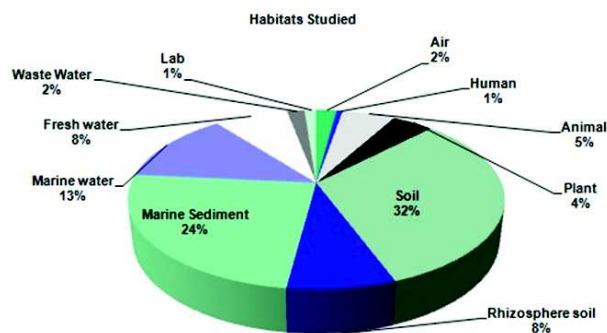


Fig. 2: Different habitats that yielded strains based on which new species of prokaryotes are described from India during the decade 2006-2016

International Journal of Systematic and Evolutionary Microbiology (IJSEM), we have not included them in the list here since we included only those species that are described according to “bacteriological code” (International code for Nomenclature of Prokaryotes ICNP) alone. Less than 10 new taxa of *Cyanobacteria* were described from work done in India in the last decade (Keshari *et al.*, 2016; Prashanth *et al.*, 2016a, b) according to botanical code International Code of Nomenclature for algae, fungi and plants (ICN).

A single new species was described in a large number (127) of genera. Most of the genera (63%) contain less than 1% of new species described (Fig

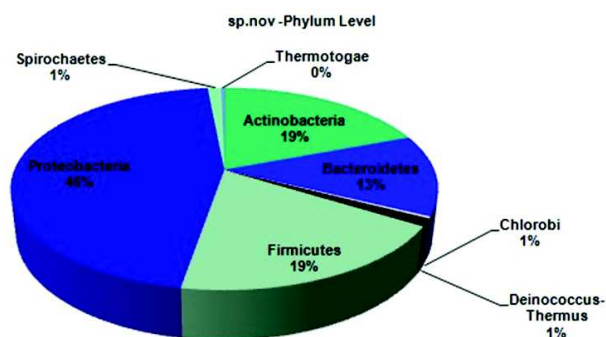


Fig. 3: Different phyla in which new taxa of prokaryotes were described from India during the decade 2006-2016

4). Maximum number of species are described in the genus *Bacillus* (22, ~7% of total descriptions from India) of *Firmicutes* and the genus *Streptomyces* (15, 5% of total descriptions from India) of *Actinobacteria*, followed by the phototrophic purple non sulfur bacterial genus *Rhodovulum* (11, 4% of total descriptions from India).

Physiological Groups of Bacteria in which New Species are Described

Most of the new bacterial species described (Fig. 5) are aerobic amounting to 67% followed by anaerobic bacteria (24%), and a much smaller percentage (9%)

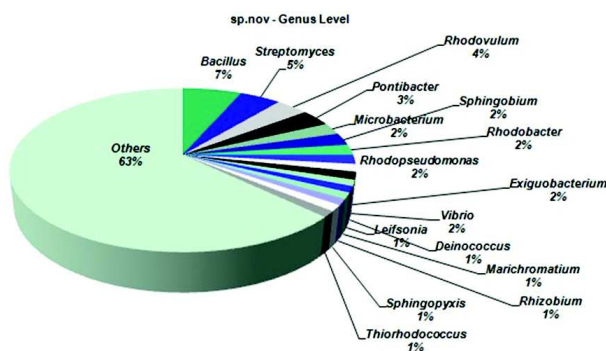


Fig. 4: Different genera of prokaryotes in which new species were described from India during the decade 2006-2016

is facultative. Only one group in India (JNTUH/UoH) is working on anaerobic bacteria belonging to the physiological groups, anoxygenic phototrophic bacteria (one order, one family, 4 genera and 58 species), spirochetes (2 genera, 5 species, one candidates genus and species each), clostridia (1 species) and sulfate

reducing bacteria (1 genus 2 species). A significant number of new species are also phototrophs (17%) though most are chemotrophs (83%) (Fig. 6).

Though most of the new species described are not extremophiles, considerable numbers are cold loving, isolated from the Antarctica and Arctic (Shivaji *et al.*, 2015). Description of candidate taxa is also recorded (Shivani *et al.*, 2016a).

Institutes Contributing to Descriptions of New Species

In general, Universities [Jawaharlal Nehru Technological University Hyderabad (JNTUH) University of Hyderabad (UoH), University of Delhi

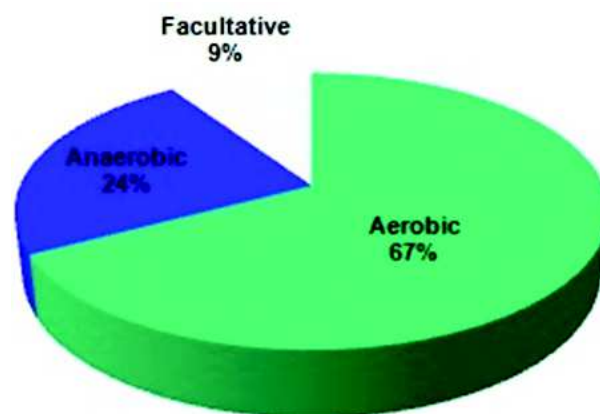


Fig. 5: Relation to molecular oxygen among new species described from India during the decade 2006-2016

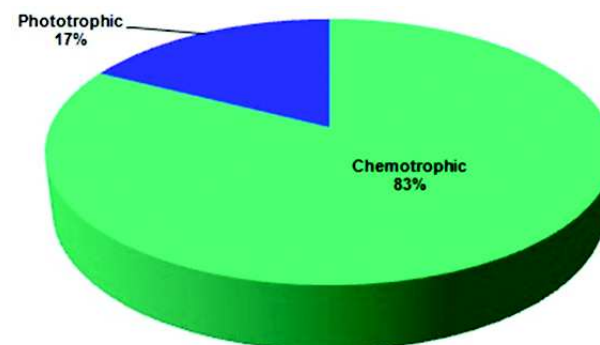


Fig. 6: The distribution of phototrophs and chemotrophs among new species descriptions from India during the decade 2006-2016

(UoD), Tamil Nadu Agricultural University (TNAU)] are the places where most of the research work leading to taxonomic descriptions of new taxa of prokaryotes is taking place followed by microbial

culture collection centres [Microbial Type Culture Collection (MTCC) of Institute of Microbial Technology (IMTECH), Chandigarh, Microbial Culture Collection (MCC) of National Centre for Cell Science, Pune] and national labs (Centre for Cellular and Molecular Biology (CCMB), National Institute of Oceanography (NIO), Institute of Life Sciences (ILS), Bhubaneswar) (Fig. 7). Small and newer universities like Mahatma Gandhi University, Nalgonda and Palamuru University, Mahabubnagar are also contributing significantly to new taxa descriptions. M.S. Swaminathan Research Foundation, Chennai is the only non-governmental organization contributing to description of novel taxa. Yenapoya University, Mangalore and Kalinga Institute of Industrial Technology (KIIT University), Bhubaneswar, are the only institutes in the private sector, and most of the Universities contributing to new descriptions are publicly funded (Central and state universities). Manipur University is the only university from the Northeast which has published 2 new taxa descriptions of prokaryotes, which they did in collaboration with Yunnan University China (Nimaichand *et al.*, 2013; Ningthoujam *et al.*, 2014). North East Institute of Science and technology also has described novel species in collaboration with MTCC (Kaur *et al.*, 2011). Most of the descriptions are taking place without any foreign collaboration (Fig 7). However, collaborations within the country are also happening (Shivaji *et al.*, 2006; Saha and Chakrabarti 2006; Arunasri *et al.*, 2008).

Description of novel taxa of prokaryotes out of work done in India dates back to the year 1955 and several taxa names are included in the 1980 approved list of bacterial names (Skeman *et al.*, 1980). In the last decade CCMB was the first institute to publish description of new taxa of prokaryotes. This institute has described its first new taxa in the year 1989 and has to its credit more than 60 new species descriptions of prokaryotes. In this decade it has around 32 (7% of total descriptions during this decade) of descriptions from India to its credit (Fig. 4). It may be noted that because of collaborations, the same taxa description is credited to more than one institution. The leading institutes are JNTUH and UoH who are publishing collaboratively (116), followed by MTCC (46) and University of Delhi (39%). While some groups are primarily working on bacterial diversity of diverse habitats (UoH, JNTUH) or selected habitats (CCMB) for other groups taxonomic descriptions are byproduct of their work on other aspects like hexachlorocyclohexane degradation (Malhotra *et al.*, 2012; Verma *et al.*, 2009; Anil *et al.*, 2008; Singh *et al.*, 2015).

Journals where New Taxa Descriptions are Published

More than 90% of all the descriptions are published in the International Journal of Systematic and Evolutionary Microbiology (IJSEM), the official journal of International Union of Microbiological societies (IUMS) (Fig. 5). According to “bacteriological code” (Rule 27, Lagpage *et al.*, 1990;

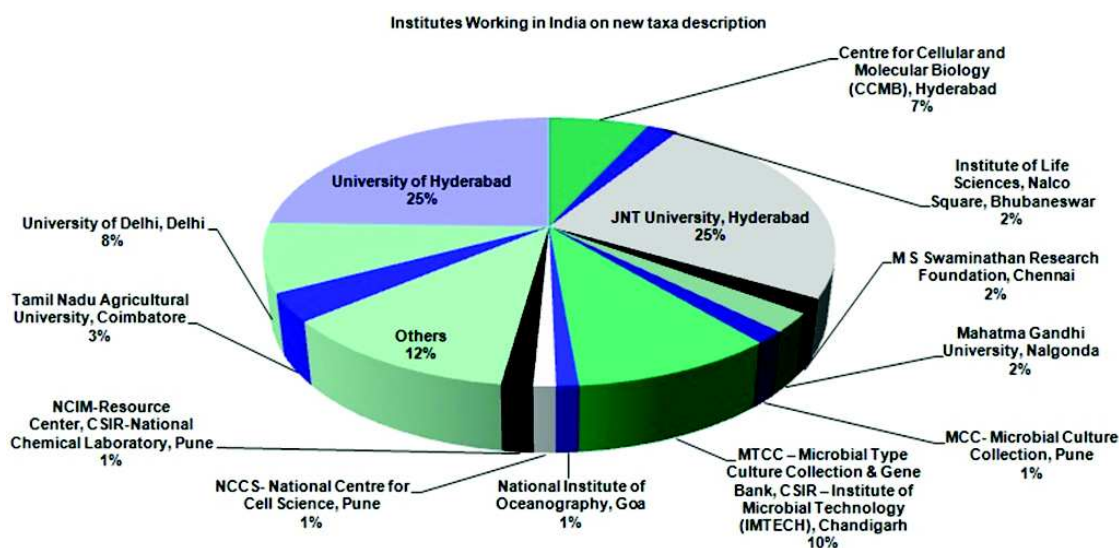


Fig. 7: Institutions where research work leading to new species descriptions were carried out

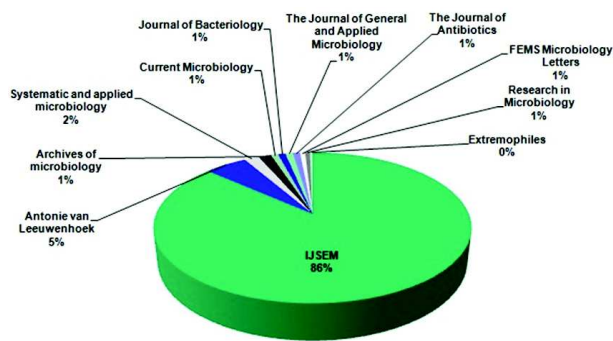


Fig. 8: Journals in which new species descriptions of prokaryotes are published during the decade 2006-2016

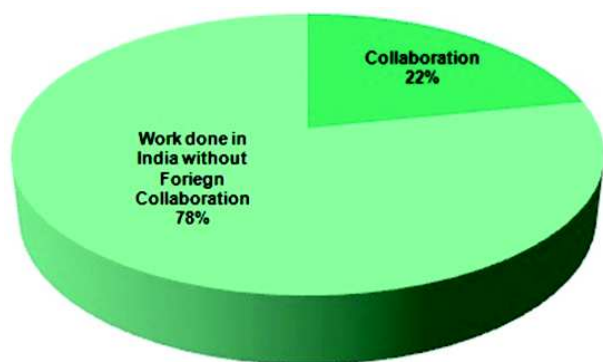


Fig. 9: Publications from India on new species descriptions with and without foreign collaboration

Table 1: Taxonomic description of pokaryotes from India during the decade 2006-2016

Taxonomic description	Number
Domain	0
Phyla	0
Class	0
Order	1
Family	1
Genus	52
Species	332
Genus emendments	24
Species emendments	6
Reclassifications	45
Subspecies	2
Candidatus	3

Parker *et al.*, 2015) only those descriptions published in this journal directly or through “List of new names and new combinations previously effectively published but not validly published” when published elsewhere are considered as validly published. It may be noted that the phrases “validly published names” or “valid description of species” needs to be used. Most of the small percentages of descriptions published elsewhere are also validated through publication in the list.

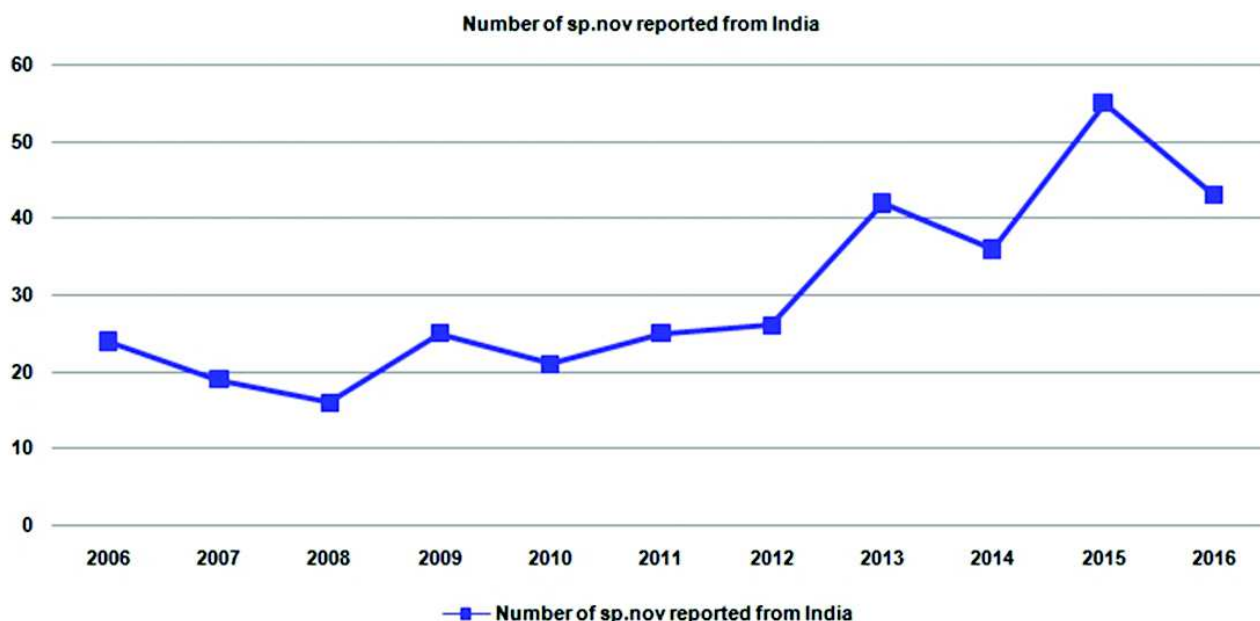


Fig. 10: Year wise species descriptions from India during the decade 2006-2016

However, *Prosthecochloris indica* (Anil et al., 2009) could not be validated for want of second certificate of deposition which is mandatory for such publication in the list of IJSEM, mentioned above.

Though *Mycobacterium indicuspranii* was suggested as a new species in PLOS One journal (Saini et al., 2009), it is not comprehensively characterized including, DNA-DNA hybridization which is mandatory for strains showing more than 97% 16s rRNA gene sequence similarity with type strains of closely related species. In addition the species epithet should have only one word according to rule 12a of “Bacteriological Code” (Lagpage et al., 1990; Parker et al., 2015) and not two as is suggested.

New/unique Methods Applied for Taxonomic Characterization

Apart from various techniques of polyphasic characterisation which the rest of the world is following (Logan et al., 2009) Indian researchers are also applying new methods like *in silico* barcoding based on MLSA analysis (Shivali et al., 2012) for taxonomic characterisation. Use of metabolomics

data is a unique contribution ranging from FTIR (endometabolome, Arunasri et al., 2008), UV/Visible spectra (Ramana et al., 2010) and LCMS analysis (exometabolome, Sravanthi et al., 2016; Srinivas et al., 2016). Genome based taxonomy also is increasingly being used (Shivani et al., 2016 b) as also found globally.

Undoubtedly, the last decade has seen increase in number of new taxa descriptions along with an increase in number of institutes involved in taxonomic work leading to description of new taxa of prokaryotes. However, it is just a miniscule compared to the potential available with vast area and diverse ecosystems of India. A systematic survey of diverse ecosystems using high throughput innovative techniques like i-chip and other microfluidic devices (Nicholas et al., 2010) is sure to result in exponential increase in novel taxa descriptions of prokaryotes from India.

Acknowledgements

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