Scientific research: a collaborative endeavour is unrivalled

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During the last few decades, advances in biology have motivated inventions in the form of bioinspired solutions. Such advances have resulted from the use of inter-disciplinary approaches to complex problems. Because of the specialized nature of tackling research problems, these scientific and technological developments have required collaborations with schools of different specialities. We emphasize the importance of such collaborations using as an example of our success with a small research programme in a teaching college, and to stress that the sum is greater than the parts in these joint global endeavours.

Over the years, research activities have shifted from individual efforts to collaborative endeavours[1,2]. Research collaborations are becoming more common in biology, mainly due to the tremendous advances in molecular and computer-aided methods[3]. By referring to our four decades of research in a college essentially committed to teaching more than research, we emphasize the importance of collaboration in research for a more complete appreciation of the chosen problem for study, as well as for the benefit accrued in terms of expertise, manpower training and enhanced recognition.

In the early 1980s, the authors joined two colleges in Chennai as lecturers. Our duties involved teaching botany to undergraduate and postgraduate students. With teaching as the primary focus, these colleges were not equipped for conducting even elementary research. Having completed our Ph.Ds from the Centre for Advanced Studies in Botany (CAS), University of Madras, Chennai and mentored by stalwarts like C. V. Subramanian, R. Kalyanasundaram and R. N. Swamy, two of us –T.S.S. and V.M. – were bitten by the research bug and started research in our college on the dynamics of mycelial growth in fungi – a choice made more because of the availability of only a quality microscope. Our senior researchers R. Balasubramanian, S. Raghu Kumar and A. K. S. K. Prasad of CAS, research colleague G. Suresh (SPIC Science Foundation) and our former student, R. Baskar of IIT Madras, motivated us in this venture. With J.P.R. joining us as the first Ph.D. student, we started looking at the adaptations of fungi to survive in marine environment.

In the late 1980s, we began to study endophytic fungi (EF) that are a part of the plant endobiome and survive within its living tissues. Although their existence was known as early as 1886 (ref. 4), there were hardly any studies on EF until 1990s (refs 5, 6). Studies on EF have increased markedly in the last couple of decades due to the findings that they produce many pharmaceutical and other technologically useful bioactive compounds[7], and enhance tolerance in their host plants to abiotic[8] and biotic stresses[9]. Today, our research laboratory VINSTROM setup by the Ramakrishna Mission Vidyapith, Chennai, houses the largest collection of EF in Asia[10]. It has trailed new paths in the study of EF of mangrove plants, forest trees, marine algae, seagrasses and lichens. Till date, our papers have been cited 4539 times. If these are worthwhile achievements by teachers from colleges where research is not mandatory, it is due to the collaborations we forged with scientists from other institutions.

Research collaborations are of different shades

Scientific collaboration is a working relationship between two or more people, groups or organizations sharing expertise, credibility, material and technical resources, and social capital[11]. Many kinds of research collaborations are recognized: between teacher and pupil, among colleagues and among organizations[12]. We gained substantially from such collaborations.

Non-formal collaboration

Non-formal collaboration could include receiving suggestions and guidance from those with expertise overlapping with one's field of research, or sometimes even from unrelated fields. Our shift of research from marine fungi to EF was due to informal discussions with late Ramesh Maheshwari (IISc, Bengaluru), John A. Johnson (University of New Brunswick, St John, Canada) and James F. White (The State University of New Jersey, USA). This resulted in what could be the first publication on endophytes associated with mangroves[13]. Similarly, we shared our method of culturing fungi on cellophane films with our collaborators to conduct experiments[14]. In another kind of non-formal collaboration, we requested experts in the respective fields to comment on the drafts of our publications. Based on their inputs, they were acknowledged for the help or included as co-authors in the publications after getting their approval.

Collaborations within India

EF of tropical plants were supposed to host many new fungal species[15,16]. With the hope of finding new fungal species, we screened 100 tree species from different forest types in the Western Ghats, India. This was possible because of the collaboration with Raman Sukumar (IISc, Bengaluru). Apart from helping in the collection of samples and identifying the tree species, his team exposed us to the use of various statistical methods to effectively interpret our findings. We showed that the species diversity of endophytes in dry tropical forests is limited due to the broad plant host range of some of the endophyte genera[17,18] – a finding which is affirmed by many across the world. Collaboration with Sukumar also enabled us to explore the diversity of EF of lichens from the Western Ghats[19]. Identification of some of these endophytes at the species level necessitated a molecular approach for which we collaborated with Sudhakara Reddy (Thapar University, Patiala) and T. S. Murali (Manipal Academy of Higher Education, Manipal)[20–22].

Encouraged by several studies ascertaining the biosynthetic ability of endophytes[23,24], we screened the FE in our collection for bioactive metabolites. With support from Dinkar Sahal (ICGEB, New Delhi), we showed that EF produce antimalarial metabolites effective against drug resistant malarial parasite[25]. Our collaboration with G. N. Sathyanarayana (IIT Madras) identified EF producing L-asparaginase enzyme devoid of glutaminase activity – an ideal candidate for the treatment of acute lymphoblastic anaemia in children[26]. Collaboration with Kaustuv Sanyal (JNCASR, Bengaluru), revealed that EF produce metabolites that inhibit multidrug-resistant *Candida auris*, which is emerging as a serious human pathogen (unpublished).

EF increase the biotic and abiotic stress tolerance of their host plants. Hence they could be used to improve crop resilience to climate change-induced stressors. R. Uma Shaanker (UAS, Bengaluru) is engaged in this work and we are collaborating with him[27]. In collaboration with Sumpam Tangjang (Rajiv Gandhi University, Itanagar), we reported the occurrence of culm rust fungus (*Stereostratum corticoides*) on a bamboo species (*Phyllostachys bambusoides*) from the Ziro valley, Arunachal Pradesh, India.

Collaborations outside India

The funding of international projects by the Department of Biotechnology (DBT), Government of India (GoI) aided in VINSTROM collaborating with international research groups. The potential of EF for producing novel bioactive metabolites was addressed in collaboration with Florenz Sasse (Helmholtz Centre for Infection Research, Braunschweig, Germany)[28]. In this project, our students learnt different bioassay techniques. Our collaboration with Bruno Moerschbacher (University of Muenster, Germany) was mutually beneficial and demonstrated that EF area novel source of chitin-modifying enzymes[29]. Work with Stefan Vidal (Georg-August-University, Gottingen, Germany) addressed the ability of EF as biological control agents[30]. With Petr Karlovsky (Georg-August-University) we demonstrated that endophytes in betel leaves produce mycotoxins[31]. Our discovery of extreme thermotolerance of spores of mesophilic endophytes from forests experiencing frequent fires was confirmed by Nicholas Money (Miami University, Ohio, USA). This and our findings that EF survive in plant litter as saprotrophs encouraged us to examine the potential of endophytes for biomass degradation. We studied this in collaboration with Venkat Gopalan (Ohio State University (OSU), USA). This culminated in many research publications revealing novel biomass-degrading enzymes from EF[32–36]. Consequently, we collaborated in a joint European project involving Kaisa Marjamaa (VTT Technical Research Centre, Finland), Priit Valjamae (University of Tartu, Estonia) and Jochen Buechs (RWTH Aachen University, Germany) to look for novel inhibitor-resistant lignocellulolytic enzymes from EF. Collaboration with R. Geeta (State University of New York, Stony Brook, USA) confirmed that *Phomopsis* as an endophyte is not host-restricted[37]. These cross-border collaborations helped our students to receive training in different techniques and also broaden our research capability, enabling us to write stronger research proposals for funding.

Collaboration means mutual gain

Although the most obvious outcome of research collaboration is joint publications which increase the visibility of the authors and enhance their citation index[2], there are more aspects to this exercise. One such is the sharing of acquired expertise between the participating teams. VINSTROM helped the Honors section of Biology, OSU to introduce an endophytes research project which was received well. The 'students participating in this project exhibited gains in scientific literacy, and acquired knowledge of and interest in pursuing scientific careers' (personal letter to T.S.S. from C. Breitenberger, Director, Center for Life Sciences Education, OSU). T.S.S. introduced the study of endophytes in the State University of Amazon (Universidade do Estado do Amazonas – Brazil), Kenyatta University (Kenya), University of Muenster, and OSU. Based on the experience gained from our collaboration, Dinkar Sahal studied the antimalarial potential of several EF of plants from Cameroon[38]. We gained experience in the study of chitin-modifying enzymes, biomass-degrading enzymes and bioassay-guided fractionation due to collaborations with foreign scientists. Another advantage of collaboration is the merging of different specialities to enable publications highlighting border issues. With the entomologist A. Raman (Charles Sturt University, Orange, NSW, Australia), we published a review exploring the patterns of relationships between insects, plants and EF[39].

How to go about seeking research collaboration?

Generally, the less known a laboratory is, fewer are its chances of attracting collaborators. This was true for VINSTROM as well. However, in the early 1980s, the chances of collaboration turned bright as the laboratory started focusing on a less-studied group of organisms, viz. the fungal endophytes. A few initial publications from VINSTROM in standard journals underscored our unique expertise and impressed the scientist whom we requested for collaboration. Thus, it is important that the collaboration seeker has some distinctive specialization to complement the requirements of potential collaborators. When different expertise and experience come together, the results could be profitable to the groups, institutions and scientific fields[40].

Financial resources for collaboration

Financial constraints could be a key restriction for the otherwise possible collaborations between research groups. VINSTROM overcame this limitation by obtaining funding from the various Central Government Departments in the country. These include DBT (8 projects), Department of Science and Technology (1), Ministry of Environment, Forests and Climate Change, GoI (2) and the Indian Council of Forestry Research and Education (1). Financing organizations need proof regarding the research capabilities of the laboratory seeking funding. To a great extent, this is reflected by the quality of publications emanating from the laboratory. Hence, small laboratories with minimal or no funding face a peculiar situation of 'no funding without publication and no publication without funding'. This vicious circle has to be

broken to make a beginning. Self-financing, donations and seed funding by the parent organization of a laboratory could be helpful in such situations.

Conclusion

Apart from improving scientific expertise and getting more publications, and proposing stronger grant applications[41], collaborations could reveal scientific results which remain cryptic when explored individually[42]. Also, smaller institutions should not be shy to seek collaboration with bigger ones, and well-established institutions should not shun viable collaborations with lesser known ones.

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