Recent Trends in PGPR Research for Sustainable Crop Productivity

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ROLE OF PUBLIC-PRIVATE PARTNERSHIPS IN BIOPESTICIDES AND BIOFERTILIZERS RESEARCH AND DEVELOPMENT FOR SUSTAINING AGRICULTURE PRODUCTION

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ABSTRACT

Public-Private-Partnerships (PPPs) are important in involving private sectors for harnessing their efficient and enhanced mass production and delivery of consumer products and services. In agriculture, the rationale for these bilateral or multilateral collaborations is to achieve sustainability in agriculture production. In agriculture research and development (R&D), these PPPs are effective in overcoming public sector institutions limited ability in taking research products and technologies effectively to farmers. This paper emphasizes the role of PPPs in biopesticides and biofertilizers research towards attaining sustainability in agricultural production. The challenges faced by the smallholder farmers in Asia-Pacific region; the benefits of integrating modern and indigenous technologies and materials for increased food production arediscussed in the paper. Particularly, the role of Plant Growth-Promoting Rhizobacteria (PGPR) in sustainable agriculture production, their mechanisms of action in controlling plant diseases and promoting crop yields were highlighted. The role of Asian PGPR Society in building fruitful collaborations among scientific institutes, private enterprises, industries and academic institutions, and thus promoting PPPs in biopesticides and biofertilizers research are discussed. Lessons learnt from PPPs such as the Hybrid Parents Research Consortia (HPRC) model established by ICRISAT; and the Bioproducts Research Consortium (BRC) partnership with ICRISAT were elaborated. The future of PGPR research and the scope of PGPR as biofertilziers and biopesticides with commercial potential in Asia-Pacific region are discussed. The role of Governments in forging PPPs in R&D for biofertilizers and biopesticides as in case of is emphasized. The future role of Asian PGPR Society in accelerating and revitalizing the existing PPPs and facilitating the future partnerships in biopesticides and biofertilizer sector are discussed.

KEY WORDS: Public-Private Partnerships, Biofertilizers, Biopesticides, PGPR and Sustainable Agriculture

INTRODUCTION

The global population is expected to reach~8.9 billion by 2050 (United Nations Report 2004), from the current level of ~7.3 billion in 2015. Food and nutritional security becomes all the more important with the certainty of climate change scenario and the ever increasing human population. Approximately 1 billion people are poor and hungry. Nearly three quarters of the world's poor and 70% of hungry people live in rural areas, where smallholder farming prevails and nearly 2 billion people depend on them for livelihoods. These small holder farmers produce about80% of the food consumed in Asia and sub-Saharan Africa. It is estimated that about 87% of the world's 500 million smallholder farms (with less than 2 ha) are in the Asia-Pacific Region (Nagayets, 2005).The dryland farming systems in many developing countries produce low and unstable crop yields, coupled with fragile ecological balance keeping the farmers in subsistence mode. The smallholder farmers in these regions face several challenges, such as (i) high cost of chemical inputs (fertilizers and pesticides); (ii) poor soil fertility and irregular rainfall; (iii) lack of access to output markets; and (iv) difficulties in mechanization to reduce labor costs. These farmers need to be empowered to move away from subsistence to market-oriented farming (Dar, 2008).However, majority of the smallholder farmers are resource-poor, and cannot afford high-cost inputs. On the other hand, we cannot achieve food and nutrition security without external inputs for increasing agriculture productivity and sustainability in the small-scale sector. This will need supportive policies and technologies to ensure that farmers have access to appropriate technologies and inputs that are affordable and sustainable.

Modern science and technology has made significant progress in the past 4-5 decades, and has provided technologies and inputs for the farmers to increase food production. These technologies include: (i) improved crop varieties and hybrids; (ii) better options for management of soil, water and other natural resources; (iii) technologies for managing pests and diseases; and (iv) improved food processing and storage technologies. Farmer-led and farmer-participatory research and development interventions have played a major role in increasing food production by the smallholder farmers. More specifically, farmers in the third-world countries have many indigenous technologies that have been fine-tuned with modern science to manage the crops better, such as zero or minimum tillage; use of crop residues as organic soil amendments; green manuring; crop rotations; and biological control of pests and diseases. Asian region has a long history of developing and using locally available materials (local medicinal herbs, cow urine, cow dung, milk, butter milk, animal flesh and bones, etc.) to prepare concoctions that were used to manage pests and diseases in crops and also to treat sick animals (Choudhary et al. 2007). Many of the recommendations to control pests and diseases using herbs and animal products can be followed even today with good results.

PGPR, Biopesticides and Biofertilizers

One of the major drawbacks of modern agricultural technologies (sometimes referred to as Green Revolution technologies) has been the excessive and inappropriate use of chemical fertilizers and synthetic pesticides which has been reported to lead to unsustainable agriculture and environmental degradation. Biofertilizers and biopesticides (both botanical and microbial origin) are an important alternative to manage pests and diseases, when used strategically (Rupela et al. 2005). However, a major bottleneck has been the timely availability of standard quality biopesticides and biofertilizers at affordable prices, and in remote rural areas.

Plant Growth Promoting Rhizo-bacteria (PGPR) and other beneficial microbes have gained worldwide acceptance in sustainable agriculture production. More specifically, they have been exploited to a limited extent to support organic agriculture in many developing countries. Many Asian countries such as China, India, Japan, Korea, Nepal, Philippines and Vietnam are advocating use of biofertilizers and biopesticides for sustainable agriculture. Plant growth-promoting (PGP) microbes are soil bacteria that colonize rhizoplane or rhizosphere and enhance plant growth. PGP bacteria can directly or indirectly affect plant growth through various mechanisms which includes fixation of atmospheric nitrogen (Soares et al. 2006), solubilization of minerals (Basak & Biswas 2009; Panhwar et al. 2012), synthesis of various enzymes and phyto-hormones (Patten & Glick 2002), and inhibition of phyto-pathogens (Hao et al. 2011; Gopalakrishnan et al. 2011a, b). ICRISAT has a collection of over 1,500 microbes including bacteria and actinomycetes, isolated from various composts and soil rhizosphere, in which at least one out of six has documented either single or multiple agriculturally favorable traits.

Some of the actinomycetes in the germplasm collection such as *Streptomyces* spp., (such as *S. caviscabies, S. globisporus* sub sp. *caucasicus*, and *S. griseorubens)* have registered *in vitro* PGP traits such as IAA and siderophore production and positive effect on the up regulation of PGP genes such as IAA and siderophore-producing genes. *In vitro* trials have shown potential of enhanced growth in rice under field conditions via increased tiller numbers, panicle numbers, filled grain numbers and weight, stover yield, grain yield, total dry matter, root length, root volume, and root dry weight. In addition, they significantly enhanced rhizospheric total nitrogen, available phosphorous, organic carbon, microbial biomass carbon, microbial biomass nitrogen, and dehydrogenase activity over the un-inoculated control. Apart from the PGP traits, they also have the capacity to act as biocontrol agents due to the production of hydrogen cyanide and enzymes such as lipase, chitinase, and β–1,3 glucanase (Gopalakrishnan et al. 2012, 2013, 2014a, b). Other PGP actinomycetes such as *Streptomyces tsusimaensis, S. caviscabies, S. setonii,* and *S. africanus* have shown inhibitory activity against *Fusarium oxysporum* f. sp. *ciceri* (FOC) under green house and *Fusarium* wilt-sick fields (Gopalakrishnan et al. 2011b). They have also shown inhibitory action on *Macrophomina phaseolina*, a causative agent for the charcoal rot of sorghum (Gopalakrishnan et al. 2011a) under greenhouse conditions.

Role of Asian PGPR Society in promoting PPPs and Sustainable Agriculture

The "Asian PGPR Society for Sustainable Agriculture" has been making sincere efforts in this direction. However, more proactive and concerted efforts will be needed to ensure that Asian PGPR Society remains relevant in the future. Most important will be the task of ensuring that high quality PGPR and other bioproducts (including biopesticides and biofertilizers) are available to the small holder farmers in rural areas. Although a few products are available in the market, the quality of these is inconsistent and unreliable. By bringing scientists, researchers, entrepreneurs and progressive farmers on to a common platform to exchange the ideas, Asian PGPR Society can influence future directions on PGPR research for sustainable agricultural production. However, much has still to be done to visualize the biopesticide and biofertilizer research and the product application in farmer's fields on a large scale. Strong public-private partnerships are therefore essential for achieving these goals. Asian PGPR Society has also been a platform for enabling fruitful interactions among various scientific institutes, private enterprises at the international level and is leveraging the concept of establishing linkages between academic institutions and industry. It is envisaged that this will also enable in promoting the integrity of research in PGPR related areas.

Efforts should be to enhance access of reliable, high quality and affordable bioproducts in the market so that smallholder farmers can benefit from these technologies. After analyzing past successes, failures and lessons learnt in the R&D community globally, we consider that a strong Public-Private Partnership Model, similar to the highly successful ICRISAT-Private Sector Hybrid Parents' Research Consortia (HPRC), will be essential.

Hybrid Parents' Research Consortia (HPRC) Model

Public-Private partnerships in agriculture R&D are increasingly viewed as an effective means of conducting advance research, commercializing new technologies, and deploying new products for the benefit of resource-poor farmers (Gowda et al. 2009). Multilevel, strategic partnerships mobilizing science and technology for the poor is at the heart of CGIAR research. The CGIAR Centers recognize that building capacity of partners is a two-way process, where private sector partners benefit from IARC's expertise and technologies, and Centers benefit from the market experience of private sector partners. The synergies gained by a combination of social equity of the public sector research and the efficiency in product delivery of the private sector companies creating the linkages in the supply chain for delivery of inputs (in this case the seed of hybrid cultivars) to smallholder farmers (Gowda et al. 2009). Pooling of resources minimizes the risks associated with R&D, for mutual benefit and sharing of costs leads to lower product costs, thus benefiting the consumers (in this case farmers as primary consumers).

The HPRC was established by ICRISAT and a few interested Private Sector Seed Companies in 2000. The HPRC enabled ICRISAT to work synergistically and support the private sector seed companies (and also profit making public sector seed corporations) to ensure availability of quality seed of high performing hybrids (of sorghum, pearl millet and pigeonpea crops) to smallholder farmers, through

partnership-based approach. Using the vast genetic resources available in its genebank, ICRISAT conducts strategic and applied research to develop improved breeding lines and hybrid parental lines (of sorghum, pearl millet and pigeonpea), and shares these with both public sector and private sector (who are members of the HPRC) plant breeders. The PS Seed Companies select good parental lines adapted to the ecological niches and with traits that are preferred by the farmers, in their own market segments. Test Hybrids are evaluated widely in the target areas to select the best performing hybrids. Seed companies then mass produce the seed, process, pack, and market the hybrid seeds using the vast network of agro-dealers in the rural areas (Gowda et al. 2009). Involvement of a large number of companies in the consortium (at one time, more than 50 seed companies were members of one or more of the consortia) increases competition and reduces the monopolistic behavior of seed companies. Cost of hybrid seed is kept at reasonable levels by competitive forces, hence within the reach of the resource-poor smallholder farmers. Private sector seed companies are able to make good profits from the sale of improved hybrid seeds, while ICRISAT is able to show the impact of its crop improvement research in the farmers' fields.

Promoting Biopesticides and Biofertilizers through PPP

As mentioned earlier, biopesticides are important alternatives to chemical pesticides, with good track record of biosafety and efficacy when these are used strategically. Similarly, the biofertilizers have shown their merit in sustaining crop yields and improving soil fertility and health. In many cases biopesticides and biofertilizers are highly affordable, especially when these are prepared by farmers themselves or locally at the community or village level (Rupela et al. 2005). However, these locally produced products are not pure and hence their efficacy is not high nor consistent. Farmers and scientists should work together to blend modern science with traditional knowledge and practices to produce high quality products for the rural markets. On the other hand, methodological breakthroughs in molecular biology and biotechnology have strengthened microbiologists' capacity to mass multiply microbes in large quantities that was not possible in the previous decades. With the demand for organically grown foods in many countries, and in view of sustainability of agriculture in general, the demand for biofertilizers and biopesticides (including both botanicals and microbial pesticides) is increasing globally. However, supply of good quality bioproducts is not able to meet the demand. Hence, there is a need for involvement of the private sector in joining hands with the public sector researchers to ensure that the farming community is able to get quality bioproducts at affordable prices.

In view of the highly successful public-private partnership in the Hybrid Parents Research Consortium (HPRC), ICRISAT and a few private sector biopesticide manufacturing companies initiated the ICRISAT-Private Sector *Biopesticide Research Consortium (BRC)* in January 2005, that was later renamed as Bioproducts Research Consortium to include PGPR and biofertilizers (Rupela et al. 2005). Eleven biopesticides/biofertilizers companies joined the consortium as its founding members. The overall goal of BRC was to make quality biopesticides and other bioproducts to the farming community at affordable price. ICRISAT had a collection of

>1500 microbial germplasm (many with PGPR and biopesticidal properties); a few on-the-shelf technologies [such as Helicoverpa nuclear polyhedrosis virus (HNPV), and a few proven biopesticidal microbial strains], fermentation technologies, small-scale fermenters, and expertise in policy issues related to biopesticide testing and registration. On the other hand, the biopesticide/ biofertilizer companies had medium to large-scale capacity factories to manufacture bioproducts, and also the needed market linkages with a network of agro-dealers. The BRC Phase I was implemented with good success (2005-07), and Phase II was started in 2008. Unfortunately, only 3 out of 11 companies continued their membership. Without the critical mass of partners needed for a viable R&D consortium, the BRC became inoperative in 2010.

Lessons learnt from BRC experience

- Private sector companies demand and need "ready-to-use", on-the-shelf technologies that can be mass produced and launched within 1 or 2 years to maximize their profits,
- Most companies were unwilling to invest in long-term strategic and basic research at ICRISAT to develop potential future technologies,
- The CGIAR policy did not allow PS companies to use institution's (ICRISAT) name in marketing of products,
- Currently available PGPR strains were unable to show large and significant effects under varied on-farm situations to convince the farmers to use these bio-products,
- Most manufacturers were willing to produce and provide high quality products (PGPR, inoculants, biopesticides, etc.), but not willing to invest in research to ascertain why the products do not work in the real world (on farmers' fields) situations,
- Most companies wanted BRC to facilitate government clearance and lobby for favorable policies. This was initiated in Phase 2, but was not fully pursued as very few companies remained in the consortium, and
- Success of spinosad-like products indicate that purified forms of biopesticidal components do have future potential, but need large R4D investments.

The Future

PGPR microbes have multiple functions and features that promote plant growth, aid in controlling insect pests and diseases, and also in influencing soil health. However, the extent of success in realizing the benefits of PGPR tends to diminish as it moves from laboratory to greenhouse, and eventually to the farmers' fields, which reflects the scarcity of research on the effectiveness of PGPR microbes under field conditions. Therefore, generation of comprehensive knowledge on screening technologies for selection of best rhizobacterial strain for rhizosphere competence and survival is critical to enhance the field level successes. Inoculant strains that survive and are effective in varied agro-ecologies need to be promoted more aggressively so that farmer acceptance and adoption increases.

Chemical fertilizers have received government support, including subsidies, for many decades in many countries resulting in the over-use or inappropriate use of fertilizers. In order to provide a level playing field, governments should either stop subsidies to chemical fertilizers, or provide similar support to biopesticides and biofertilizers. Preferably, governments should incentivize farmers (through direct money transfers) to promote sustainable agriculture, including ecosystem services such as rainwater harvest for charging aquifers, enhancing the population of beneficial insects (natural enemies of pests) and pollinators, and beneficial microbes in the rhizosphere.

The role of governments is also critical in forging PPPs in biofertilizers and biopesticides research and development. For example, in India, Biotechnology Industry Research Assistance Council (BIRAC) is one such entity which brings together multiple stakeholders in public and private sector and work towards converting agricultural technologies into products that can reach farmers. A product in reality will always convince the policy makers in a much better way.

It is evident that there is a huge potential for PGPR microbes in biopesticide and biofertilizer industry. The market for trade in "Bioproducts" is large, both in domestic and international markets. However, what is needed is a change in mindset and attitudes of people in both public and private sector, and they should start a strategic partnership model on the lines of the ICRISAT-Private Sector Hybrid Parents Research Consortium. The Asian PGPR society should facilitate the formation of a synergistic "platform" or a "consortium" to encourage interested and committed entities and institutions to come together for mutual benefit, and to serve the farming community. The next steps of Asian PGPR Society should be to revitalize the existing public-private partnerships (PPPs); encourage and envisage the scope of future partnerships that can benefit the biopesticide and biofertilizer research exploiting the PGPR microbes. However, the models that are formulated for establishing these partnerships should be viable and mutually beneficial, besides maintaining transparency. With the overall goal of improving the livelihoods of smallholders, promoting PPPs for biopesticide and biofertilizer research and development in Asian countries is vital in the agriculture and allied sectors.

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