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Editorial Introduction

K. Ravi Srinivas*

This issue, the second in Volume 19 of Asian Biotechnology and Development Review, has articles and book reviews that discuss themes and issues that are of relevance for discussions on socio-economic development aspects of biotechnology.

Biotechnology opens up new opportunities in harnessing various types of biological resources. This has enabled more attention to previously under explored resources and their potential. Thanks to options like genome mapping it is now possible to study and understand the genetic map of all types of crops including millets and coarse grains. As there are initiatives to make them popular about the general public and enhance nutritional security, technology can play an important role in making them more useful to producers and consumers. Endophytic microorganisms that colonize plants and these microorganisms including bacteria and fungi have gained attention of plant biologists in view of their potential and beneficial uses and the scope for adopting them for different purposes. With applications in plant growth promotion, biocontrol of pathogens and pests, and as a potential source of novel biomolecules harnessing them in sustainable intensification of agriculture and developing biotechnological applications open up new opportunities. In this issue we have published an article by Dr.Pious Thomas, that describes the significance of these microorganisms in agriculture and horticulture. This article besides providing a comprehensive picture of these microorganisms, discusses their potential applications and ways to harness them. Obviously there could be years between research in them and wider adoption of applications based on them. Never the less it is important to bring to the attention of readers new and relevant research that is useful for developing countries.

Genetically Modified Organisms (GMOs) have been controversial ever since they were commercialized. Philosophers and social theorists have been

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analyzing them from different vantage points. While ownership issues and access to GMOs have been often discussed in the context of intellectual property rights and policies of the government, questions relating to ethics and innovation, responsibility and ownership have been raised and the literature on this increasing, partly on account of the concept and practice of Responsible Research and Innovation (RRI)[1]. Zoë Robaey discusses the moral responsibility of owners of GMOs using ideas from ethics and political philosophy. Such articles enable to under the issues and controversies better. In fact toady the debate on GMOs has gone far beyond accepting them or rejecting them or projecting them as villains or as a panacea. This debate can shed new light on issues relating to technology, innovation and ethics on one hand, and, enable conceptualizing new ways to incorporate ethics and values in technology development and assessment, on the other hand.

This issue carries three book reviews which cover inter alia, plant variety protection, and, RRI and agricultural biotechnologies. We welcome your feedback including suggestions.

Endnotes

1 See for example, Daniel J. Hicks (2017), Genetically Modified Crops, Inclusion, and Democracy, Perspectives on Science Volume 25,Issue 4, Pp.488-520;

Justin B.Biddle (2017), Genetically engineered crops and responsible innovation, Journal of Responsible Innovation, Volume 4, Issue 1, Pp 24-42;and,

Sheila Jasanoff (2016) The Ethics of Invention, New York: W.W.Norton & Co

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Potential Applications of Endophytic Microorganisms in Agriculture

Pious Thomas*

Abstract: Endophytic microorganisms mainly include bacteria and fungi which colonise intercellular and intracellular niches of tissues without apparent adverse effects to the host plants. There is a growing interest of plant biologists in endophytic microbiology for basically in isolation and cultivation of such microorganisms from plant organs and then demonstrating their beneficial effects on the host-plants. Present knowledge about endophytic microorganisms is that they share a mutualistic association with the host, perhaps serving as the plant- defence system, and also contributing to plant growth and fitness. Lately, there is a mounting interest in the exploration and utilization of such endophytes for plant growth promotion, as biocontrol agents against plant pathogens and pests, for alleviation of abiotic stress and for sourcing of novel biomolecules. Such characterised endophytic bacteria have been identified and described. Much research on this group of organisms originated from micropropagation research.

Tissue-culture systems form one significant tool for studying host-endophyte associations. The microbial associations bear consequential effects on the success and efficiency of in- vitro cloning / micropropagation technologies. 'Endophytology' with the concepts of 'holobiome', associated with the plant and endophytes, and 'hologenome' comprising plant genome together with the endophytes' genomes are assuming great significance in plant biology research with considerable potential applications in agriculture and many other fields.

Keywords: Endophytic microorganisms, Cytobacts, Plant growth promotion, Plant-microbe interactions, Plant tissue culture.

Introduction

The term endophyte which is derived from Greek, means 'inside the plant' (endon, within; phyton, plant) (Schulz and Boyle, 2005). This term is used to describe microorganisms residing inside plants without any obvious harmful effects on the host (Hallmann *et al.* 1997) including mainly fungi and bacteria (Bacon *et al.* 2002), with the nature of their interactions

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ranging from beneficial effects to mild pathogenicity (Hardoim *et al.* 2015). Recent definitions also cover Archaea, yeasts and protists as endophytes. Plants are known to harbour internally viruses without apparent deleterious effects, but viruses are not covered under the group of endophytes. Earlier description of endophytes was based primarily on the information generated through cultivation of organisms on enriched media, which suggested their prevalence in much lower number in relation to plant pathogens with roots being the major niche (Hallmann, 2001). With the advancements in microbiology and application of molecular tools, it is now emerging that a vast majority of endophytes are not amenable for cultivation, and there exists a huge diversity of such non-cultivable bacteria and fungi. Endophytic microorganisms do not generally include root nodules associated symbiotic nitrogen-fixers in legumes and Vesicular Arbuscular Mycorrhiza (VAM), even though they are internal colonizers and isolated from surface sterilized tissues. These have been exploited in agriculture for quite a while, much before the invigorated research on endophytic microorganisms was set in during 1980-90s.

Endophytic organisms that are abundant in soil are considered to be recruited by the plant, and they form a subset of such organisms present in the rhizosphere (Hallmann *et al.*1997; Compant *et al.* 2010). Under natural conditions, endophytic microorganisms do not show any adverse effects on the host, and they perhaps share a mutualistic association, possibly contributing to plant growth or improved fitness (Podolich *et al.* 2015; Thomas *et al.* 2017). There is a great interest in utilizing them in plant growth promotion, biocontrol of pathogens and pests, alleviation of abiotic stress and as source of novel biomolecules (Hardoim *et al.* 2008; Ryan *et al.* 2008; Gaiero *et al.* 2013). They command biotechnological applications also with particular significance in plant tissue cultures (Thomas, 2010, 2012; Mercado-Blanco and Lugtenberg, 2014). Endophytic fungi and bacteria are known to be involved in plant biochemical pathways, and the therapeutic properties attributed to some medicinal plants are apparently linked to endophytes directly or indirectly. For a microorganism to be exploited in agriculture or allied sectors, it is important that the organism is cultivable with further feasibility of scaling up. The prime aspect in describing such cultivable endophytic microorganisms depends on the efficient surface sterilization practice, which would warrant reliable techniques to remove all external organisms backed by proficient monitoring methods and sterility assurance to ward off external organisms (Thomas and Sekhar, 2017).

Endophytic microbiology research scenario

The first documented description of such organisms dates back to 1809, when German botanist, Heinrich Friedrich, described a distinct group of partly parasitic fungi living in plants against the general belief that the healthy or normal growing plants are sterile and free of microorganisms (Hardoim *et al,* 2015). Research on bacteria harbouring internal tissues of asymptomatic plants dates back to 1870s through the work of Pasteur and others (Hallmann *et al.* 1997). Interest on endophytic microorganisms grew more during the latter part of 20th century with prime focus on plant-associated fungi. A series of publications (Hallmann, 2001 and Bacon *et al.* 2002) documented colonization of different plants by various fungi, particularly of Ascomycota phylum. Several reports on the indigenous endophytic bacteria in different plant tissues emerged by mid-twentieth century. Diverse bacteria representing over 50 genera were documented during the 1980-90s. Documentation of beneficial effects such as plant growth promotion or biocontrol of pathogens and pests deepened the interest in studying endophytic bacteria. A detailed earlier account of the bacterial endophytes and their potential use in agriculture can be found elsewhere (Azevedo *et al.* 2000; Hallmann, 2001; Ryan *et al.* 2008). At present, it is well-established that plants are hosts to many types of microbial endophytes, including bacteria, fungi, archaea and unicellular eukaryotes such as algae and amoebae (as reviewed by Hardoim *et al.* 2015).

Research on endophytes in India has been abysmally low, and is of much recent origin, excluding the works on VAM and nitrogen- fixing bacteria, which are not strictly viewed as endophytic community world over. Some early references to the work on fungal endophytes is associated with Suryanarayanan *et al.* (2003), relating to biodiversity and distribution patterns of fungal endophytes in some Indian medicinal plants and isolation of certain bioactive compounds from endophytic fungi (Kharwar *et al.* 2009). Of late, a number of research groups are working on fungal endophytes centred on biodiversity and discovery of bioactive compounds of medicinal value (Suryanarayanan and Shaanker, 2015).

Emphasis on bacterial endophytes came mainly through tissue culture of horticultural crop plants. While exploring source of microbial contaminants introduced in these cultures established after extensive surface sterilization treatments, such diverse microbial entities could be described (Thomas, 2004a; 2010). Several endophytic bacteria have been isolated from different plant species with bioprospecting and plant growth promotion potential (Gayathri *et al.* 2010). Of late, different laboratories are working on isolation, characterization and possible exploitation of endophytic bacteria from cereal and other field crops and medicinal species, including application of metagenomics to understand non-cultivable bacteria (Sengupta *et al.* 2017).

The endophytic microbial niche

Endophytic microorganisms were more frequently isolated in higher numbers from roots, which indicated that they were primarily colonizers in the root tissues, inhabiting root intercellular spaces (Hallmann *et al.* 1997). Subsequently, they were retrieved from different aerial plant parts and organs although less frequently and in low abundance (Hallmann, 2001; Bacon *et al.* 2002). Rhizosphere formed the main focus and source of endophytic microorganisms during initial investigations. Thus, fungal endophytes were isolated from roots of rice, wheat, maize, cotton and soybean. It was difficult to establish the extent of internal colonization by fungal endophytes based on the cultivation unlike bacterial endophytes, which form isolated colonies from single live cells. Fungal mycelia could be recorded from root cortex and vascular stele proving their endophytic inhabitation (Bacon *et al.* 2002).

Bacterial endophytes were mainly isolated from the roots of different crops and to a lesser extent from stem, leaves, flowers and even seeds (Hallmann *et al.* 1997; Compant *et al.* 2011). They are also considered to enter plant endosphere mainly from soil through roots. Root hairs form the primary point of contact and entry (Mercado-Blanco and Lugtenberg, 2014). Entry from aerial plant parts through the natural openings such as stomata and wounds have also been documented, but that formed a very minor share compared with the root system. Bacterial endophytes are considered primarily intercellular or apoplastic colonizers, inhabiting the free spaces between cells. There are also isolated reports suggesting intercellular colonization. Lately, enormous intracellular colonization by bacterial endophytes in banana field shoot tissues and *in- vitro* cultures has been demonstrated with the adoption of live -cell imaging (Thomas and Reddy, 2013). It appears that two intracellular niches of colonization, cytoplasm and periplasm prevail; and the terms 'Cytobacts' and 'Peribacts' have been coined to describe them in the respective niches (Thomas and Sekhar, 2014). The high abundance of bacteria detected through microscopy *versus* low cultivable bacteria or colony forming units (cfu) obtained from the plating of tissue homogenate indicated endophytic bacteria to be largely non-cultivable.

Studies comparing root interior versus rhizosphere have indicated that endophytes constitute a diverse but a subset of soil microflora in the vicinity of roots (Lundberg *et al.* 2012). The organisms, however, would be constantly exposed to defence responses of host-plants to the adversities which include pathogenic microorganisms. How do endophytes escape such host defence responses is an aspect to be elucidated, to know more about plant defence systems.

Implications of endophytic microorganisms in plant-tissue cultures

Plant tissue cultures are normally considered aseptic, which implies their freedom from all microorganisms normally hazardous to cultures, and also axenic, meaning pure cultures devoid of other life- forms (Orlikowska *et al.* 2017; Thomas *et al.* 2017). This concept is now changing with the revelation of frequent association of cultivable bacteria as covert or non-obvious associates with cultured plants, and the ubiquitous association of endophytic bacteria and fungi with field plants as well as with *in vitro* raised cultures in a non-cultivable form (Thomas, 2011; Thomas *et al.* 2008a, 2008b, Thomas *et al.* 2017). While endophytes are generally non-harmful to their hosts under natural/ field conditions, tissue- cultured plants raised from surface sterilized tissues would harbour diverse microorganisms, some of which grow actively or covertly in nutrient-rich culture medium where they may grow as *in vitro* pathogens or 'vitropath' (Herman, 2004). Another set of organisms could remain in a non-cultivable form persistently or display gradual activation to cultivable form, causing havoc to tissue cultures (Thomas *et al.* 2008a, 2008b; Thomas, 2011). While *in vitro* associated organisms may contribute to plant fitness or organogenesis processes *in vitro* (Thomas, 2004 b; Quambusch *et al.* 2014), management strategies to check covertly associated or deleterious organisms may help in better exploitation of plant- tissue culture systems (Orlikowska *et al.* 2017; Thomas *et al.* 2017).

Research investigations employing shoot-tip tissues of grapevine cultivars 'Flame Seedless' and 'Thompson Seedless' revealed high levels of taxonomic diversity of endophytic bacteria documented similarly for banana shoot-tip tissues with some variations in taxonomic profile of organisms shared by two grape cultivars (Thomas *et al.* 2017). This study indicated chances of *in vitro* introduction of a multitude of bacteria in non-cultivable form through surface sterilized tissues and their survival in tissue cultures in an absolutely non-obvious or grossly unsuspecting manner. It appeared that several of the non-cultivable bacteria associated with tissue cultures are adaptable to cultivable form, the former often expressing as obvious contamination. Endophytes possess the ability to switch between non-cultivable and cultivable states, and *vice versa* when conditions for growth are not ideal (Thomas, 2011).

Endophytes hold significance in plant tissue cultures mainly as interfering organisms and contaminants. Information on the ubiquitous association of endophytes in plant tissue cultures and their periodical activation to hazardous organisms has been the key in developing sustainable micropropagation protocols. One such example is the realization of an efficient and sustainable micropropagation protocol for papaya, which offers the scope to keep the cultures for extended periods (Thomas, unpublished results). Another example is triploid seedless watermelon stock which is being actively maintained for several years. The feasibility of long-term maintenance of established cultures circumvents need for fresh culture initiation from time to time and relieves of the associated issues of microbial contamination and slow initial growth of cultures. The findings also bear significant implications in *in vitro* germplasm conservation and cryopreservation of plant tissues.

Biodiversity of endophytic microorganisms

Cultivable endophytic bacteria

Bacterial endophytes mainly belong to phylum Proteobacteria, followed by Firmicutes and Actinobacteria depending on the crops (Rosenblueth and

Martínez-Romero, 2006; Hardoim *et al.,* 2015). Gamma-proteobacteria under phylum Proteobacteria constitute the major class of endophytic bacteria similar to that generally documented for root/ rhizosphere associated organisms. The common genera under Proteobacteria include *Agrobacterium, Acetobacter, Alcaligenes, Azorhizobium, Azospirillum, Bradyrhizobium, Brevundimonas, Burkholderia, Cedecea, Citrobacter, Caulobacter, Enterobacter, Erwinia, Klebsiella, Methlobacterium, Ochrobacterum, Paracoccus, Ralstonia, Stenotrophomonas, Pseudomonas, Pantoea, Serratia* and *Sphingomonas* spp. (Chelius and Triplett, 2001; Hallmann, 2001; Mano and Morisaki, 2008; Thomas *et al.,* 2007; 2008b; Thomas and Soly, 2009; Sekhar and Thomas, 2015.

Spore-forming bacteria belonging to phylum Firmicutes and family Bacillaceae which include the genera *Bacillus, Brevibacillus, Paenbacillus, Lysinibacill0us*, *Oceanobacillus, Virgibacillus* etc., and non-sporulating ones, predominantly *Staphylococcu*s spp. have been presently documented as endophytes. Earlier spore-forming organisms were viewed as accidental or environmental contaminants. With the improvements and the advancements in bacterial culturing, an increasing share under the phylum Actinobacteria is isolated as endophytes from different plant species and organs. They include *Actinomyces, Arthrobacter, Brachybacterium, Brevibacterium, Cellulomonas, Corynebacterium, Curtobacterium, Kocuria, Kytococcus, Microbacterium, Micrococcus, Rhodococcus, Rothia, Streptomyces, Tessaracoccus* and *Tetrasphaera* spp. (Bacon and Hinton, 2006; Thomas et al. 2008b; Thomas and Soly, 2009; Sekhar and Thomas, 2015; Upreti and Thomas, 2015; Thomas and Sekhar, 2017). A few reports have also shown members of phylum Bacteroidetes; these include *Flavobcaterium* and *Chryseobacterium* (Bacon and Hinton, 2006; Upreti and Thomas, 2015). The list of common genera of endophytic bacteria isolated from different crop plants can be found elsewhere (Bacon and Hinton, 2006; Thomas, 2012; Hardoim et al. 2015).

Cultivable endophytic fungi

Endophytic fungi mainly consist of members of Ascomycota (Bacon *et al.,* 2002; Sun and Guo, 2012). Common genera isolated from different plant sources are *Acremonium, Botrytis, Cladosporium, Colletotrichum, Curvularia, Fusarium, Phomopsis, Penicillium, Pestalotiopsis, Phyllosticta* and *Trichoderma (*Nair and Padmavathy, 2014; Lugtenberg *et al.,* 2014; Abdelfattah *et al.,* 2016). Members of Basidiomycota, Zygomycota and Oomycota are also isolated as endophytes (Sun and Guo, 2012). Yeasts are not commonly isolated as endophytes, except for a few instances, such as in grapes.

Biodiversity analysis through molecular approaches

Several studies have attempted assessment of endophytic bacterial / fungal diversity with PCR-based ribotyping approach, focusing on small subunits of ribosomal RNA in bacteria and additionally ITS regions in fungi. Other techniques such as denaturing gradient gel electrophoresis (DGGE) and terminal restriction fragment length polymorphism (T-RFLP) were also employed by many researchers. Such studies have brought to light additional organisms which were normally not amenable to cultivation, particularly bacteria (Garbeva *et al.* 2001; Conn and Franco, 2004; Reiter and Sessitsch, 2006).

Metagenomics has evolved as a powerful tool to elucidate microbial diversity exploiting speed, precision and power of the next generation sequencing (NGS) technology and bioinformatics tools (Knief *et al.* 2014). Application of metagenomics to study endophytes has brought to light unprecedented microbial diversity, particularly of bacterial endophytes. Two such remarkable studies with *Arabidopsis* root system revealed taxonomic variability spanning across >20 phyla (Bulgarelli *et al.* 2012; Lundberg *et al.* 2012). A similar study by Sessitsch *et al.* (2012) on rice documented taxonomic and functional characteristics of endophyte community colonizing roots.

The NGS-based studies targeting 16S rRNA gene hypervariable region have helped in unearthing immense bacterial diversity to the tune of 20 plus phyla in the shoot-tip tissues of banana (Thomas and Sekhar, 2017). The predominant phylum is Proteobacteria, followed by Firmicutes, Actinobacteria, Bacteroidetes, Planctomycetes, Cyanobacteria and minor share of several candidate phyla, besides the domain Euryarchaeota. Distribution at genus level indicates over 260 genera and about 650 predicted species. A comparative cultivation based analysis has shown only three phyla (Proteobacteria, Actinobacteria, Firmicutes) with only 2.5 Percent of the deciphered genera retrieved through cultivation. This has endorsed that a large share of bacteria reside as non-cultivable organisms. More than 1 million species of endophytic fungi are estimated to exist based on a ratio of vascular plants to fungal species of 1:4 or 1:5 (Sun and Gou, 2012). Metagenomics has also proven effective to study endophytic fungal diversity (Abdelfattah *et al.* 2016).

Application of Endophytic microorganisms in agriculture

Endophytic microbiota and manifold interactions between the plant associated microorganisms, including pathogens, have a profound influence on the function of the plant system and development of pathobiomes (Brader *et al.* 2017). It is now to be considered as a whole unit comprising plant together with all associated organisms, termed as the 'holobiont', or plant genome together with the genome of all associated microorganisms, termed as hologenome or pangenome (Nogales *et al.* 2015; Vandenkoornhuyse *et al.* 2015).

The most significant aspect of research on endophytic microorganisms is their potential for exploitation in agri/ horticulture (Hardoim *et al.* 2008; Ryan *et al.* 2008). Tests on the metabolic potential of the cultured organisms pointed many of them as producers of plant hormones such as auxins, cytokinins and gibberellins. Several organisms have displayed potential for nitrogen fixation/ assimilation, phosphate solubilisation and/or better nutrient uptake (Mercado-Blanco and Lugtenberg, 2014). Endophytic bacterial populations in citrus plants interact with *Xylella fastidiosa* and govern defense response (Araújo *et al.* 2002). Internal bacterial communities of field-grown potato- plants included several organisms with pathogen antagonistic abilities and growth-promoting effect on the host (Sessitsch *et al.* 2004). Tomato cultivars resistant to the bacterial wilt pathogen *Ralstonia solanacearum* showed a relatively higher diversity of endophytic bacteria compared with the susceptible lines. In addition, the resistant cultivars displayed higher share of antagonistic agents against this pathogen compared with the susceptible lines, indicating a possible role of endophytic bacteria in protecting crop against the pathogen (Upreti and Thomas, 2015). Most endophytes act as commensals without any known effects on their plant hosts. In native plants, endophytes could be involved in various plant processes and metabolic pathways and might perhaps have been engaged in direct confrontation with invading pathogens and pests. Thus, endophytes may be involved in offering a protection system parallel to the immune system in animals (Podolich *et al.* 2015; Thomas *et al.* 2017). Areas where endophytic microorganisms are utilized or exploited in crop production include plant growth promotion, biocontrol of pests, and pathogens and mitigation of abiotic stress and others.

i) Plant growth promotion

Endophytes in agriculture contributed in improving growth and yields of different crops (Hallmann, 2001; Hardoim *et al.* 2008). About 10% of the bacterial endophytes from potato- tubers showed plant growth promotion effects while rice inoculated with endophytic diazotroph *Azocarcus* sp. promoted significantly plant growth (Hallmann *et al.* 1997). Plant growth regulators such as auxins, cytokinins and gibberellins produced by the microorganisms out as agents of growth promotion. Another major effect on plant growth promotion may be due to nitrogen fixation and/ or nutrient solubilization. The suppressing deleterious microflora by the introduced organisms also indirectly contributed to enhanced plant growth. Plant growth promotion by consortia of bacterial genera was reported for oilseed rape and tomato, rice and soybean (Mercado-Blanco and Lugtenberg, 2014). Root growth promotion in papaya seedlings by endophytic strains of *Pantoea* and *Enterobacter* spp. (Thomas *et al.* 2007), application of endophytic bacteria *Pseudomonas oleovorans* for organical seedling production in tomato (Thomas and Upreti, 2016), and plant growth enhancement with endophytic rhizobacterial *Bacillus* strains in rice (El-shakh *et al,* 2015) are other examples.

ii) Control of fungal and bacterial diseases

Endophytes can be a promising tool for biological control and suppression of plant diseases (Backman and Sikora, 2008; Dutta *et al.,* 2014; Larran *et al.* 2015; Hong and Park, 2016). They colonize a niche similar to vascular pathogens and thus form choice candidates for biological control of vascular wilt-inciting pathogens (Hallmann *et al.* 1997). Endophytic bacteria have been noticed to control *Fusarium oxysporum* f. sp. *vasinfectum* in cotton, *F. oxysporum* f. sp. *pisi* in pea and *Verticellium albo-atrum* in cotton (Hallmann, 2001). Use of endophytes to control pathogens has been generally more focused on soil-borne organisms. Isolation and characterization of endophytic streptomycete antagonists of Fusarium wilt pathogen from surface-sterilized banana roots (Cao *et al.* 2005), control of lettuce drop caused by soil- borne pathogen *Sclerotinia sclerotiorum* by endophytic *Streptomyces exfoliates* (Chen *et al.* 2016), plant protection activity in Indian popcorn seedlings inoculated with endophyte *Bacillus amyloliquefaciens* subsp. *subtilis* against *Fusarium moniliforme* (Gond *et al.* 2016) are promising examples of endophytes in biocontrol of pathogens. Endophytic bacteria and their secondary metabolites were found promising to control grapevine pathogens and diseases (Compant *et al.* 2013). Such bacteria may also be good inducers of plant defence mechanism besides exerting direct antagonistic effects on fungal and bacterial pathogens. By combining plant-growth promoting organisms with pathogen antagonistic endophytic microorganisms, a holistic biocontrol strategy can be developed.

iii) Insect-pest Management

Endophytic fungi producing toxics against insect- pests offer scope for suppressing them (Azevedo *et al,* 2000). Wherever metabolites produced by the endophytes form the mechanism of pest control, increasing their population would enhance biocontrol efficacy. Detrimental effects on herbivorous insects feeding on plants harbouring endophytic fungi such as *Beauveria bassiana, Metarhizium anisopliae* and *Lecanicillium lecanii* offer scope for their agricultural exploitation (Vidal and Jaber, 2015). Control of soil-borne pests such as nematodes which are generally difficult to control has been feasible with the use of antagonistic microorganisms. *Pseudomonas fluorescens, Brevundimonas vesicularis* and *Serratia marcescens* are known to be good antagonistic agents against root- knot nematode *Meloidogyne incoginta* in cotton (Hallmann, 2001). Control of nematodes is more complex than of fungal and bacterial pathogens as they are robust organisms with thick cuticular protection and strong stylet that allows intra-plant movement with voracious feeding. Endophytic microorganisms may control them better when they are in sedentary phase soon after infection (Hallmann, 2001).

iv) Abiotic stress management in crops

Enhanced tolerance to abiotic and environmental stresses has been attained with endophytic microorganisms (Vardharajula *et al.* 2017). Improved plant metabolism leading to higher root growth, water uptake and reduced damage under adverse environmental conditions (extreme cold or drought or such others) have been ascribed to the support to plants from endophytic bacteria and fungi. In recent times, there has been an increasing interest in utilising such promising fungal endophytes to alleviate abiotic stress in crop production (Singh *et al.* 2011). Ahmad *et al.* (2015) reported the strong influence of endophytic *Trichoderma harzianum* as beneficial to mustard plants when grown with sodium chloride (200 mM) stress (as simulated in saline soils), showing elevation of shoot and root length and dry plant weight. Bacterial endophyte, *Burkholderia phytofirmans* PsJN facilitated cold acclimation of grapevine by modulating carbohydrate metabolism (Fernandez *et al.,* 2015). Plant growth-promoting endophyte bacterium, *Sphingomonas* sp. LK11 helped alleviating salinity stress in *Solanum pimpinellifolium* (Khan *et al.,* 2017).

The prime requirements for utilization of such beneficial organisms include the ability to easily culture them and maintain them with good biological efficacy in the crop fields. In order to select potential applied culturable endophyte microorganism to survive in soil, they required to be evaluated along with their biofitness and bioefficiacy. Considering hostile and fluctuating agroecology, the biofitness of such candidate organisms can be the determinant for their good potentiality (Tyc *et al.* 2014, Thomas and Sekhar, 2016).

v) Endophytes for Bioremediation

Engineered endophytic bacteria have been explored for improved phytoremediation effects of water-soluble, volatile, organic pollutants (Barac *et al.* 2004). Ability to degrade such class of toxic chemicals to less toxic forms and capability to remove toxic elements from affected soils are recorded (Doty, 2008; Ijaz *et al.* 2016). Endophytes return to soil or the environment at the end of the life of the plant or the tissue. They could be integrated to organic manure with the feasibility of improving carbon status of the soil. This implies their role in soil amelioration and organic / humus build- up.

vi) Endophytic microorganisms as source of novel biomolecules

Antimicrobial and insecticidal properties of biomolecules from endophytes have potential use in targeting plant pathogens and insect pests (Dutta *et al.* 2014). Many naturally occurring phytochemicals available in plants can actually be ascribed as the metabolic products of endophytic microorganisms (Strobel *et al.* 2004; Hardoim *et al.* 2015). One typical example is the production of anticancer drug Taxol by *Pestalotiopsis microspora*, an endophyte of Himalayan yew-tree, *Taxus wallichiana* {Maheshwari, 2006). The endophytic actinobacterium, *Pseudonocardia* sp. strain YIM 63111, enhances production of antimalarial compound artemisinin in host-plant *Artemisia annua*. Some such metabolites may be produced in the plant due to their endophytic flora (Brader *et al.* 2014). There are number of instances where medicinal properties originally attributed to the plant are identified as the properties of the endophytic bacteria / fungi.

Bioprospecting of plant microbiomes is gaining more and more attention. There is a growing demand for new bioactive compounds and biologicals from the industries such as pharmaceutical / agroindustries and food processing industries. Endophytic microorganisms, being producers of novel secondary metabolites, shall be responsible for drugs that are available in medicinal plants. A number of bioactive compounds (e.g. camptothecin, diosgenin, hypericin, paclitaxel, podophyllotoxin, vinblastine) have been commercially produced by different endophytic fungi in respective medicinal plant species (Gouda *et al.* 2016). Due to their highly specialized and co-evolved genetic pool, plant microbiomes host a rich secondary metabolism; unique and yet untapped properties of plant-associated microbiomes, which can be an immense treasure box for future research (Müller *et al.* 2016). A recent analysis of the diversity of endophytic bacterial isolates of medicinal ginseng suggested high cultivable bacterial variability differences, variation in community composition from one site to another and from one host compartment to another. Some of these bacteria also possess ability to promote plant growth (Chowdhury *et al.*2017).

vii) Utilisation of endophytic microorganisms for improved micropropagation

Improved plant performance or rooting *in-vitro* with the use of endophytic bacteria has been reported (Nowak, 1998; Herman, 2004; Thomas, 2004b). Use of endophytes for tissue culture applications is subject to condition that organisms would not display any obvious growth on the tissue culture medium or exert any adverse effects on the cultures. *Bacillus pumilus* isolated from grapes as an alcohol tolerant and covert endophyte showed root growth enhancement in grape microcuttings in *in vitro* (Thomas, 2004b), while in chrysanthemum it displayed shoot proliferation without externally supplied growth regulators (Thomas *et al.* 2009). Bacteria which do not grow actively in plant tissue culture medium can be employed in tissue cultures for one time at rooting step just prior to *ex vitro* planting. It would not be advisable to use such microorganisms continuously as they may gradually pose threat to the cultures (Thomas *et al.* 2007). Crop genotypes that are recalcitrant or difficult to respond with effective regeneration or rooting in culture can be benefitted with the inoculation of the identified beneficial bacteria. For instance, *Rhodobacter sphaeroides* producing phytohormone rodestrine enhanced rooting of mulberry microshoots and *Bacillus* spp. producing IAA promoted rooting of strawberry (Orlikowska *et al.* 2017).

Another major area of application of endophytes during micropropagation is at rooting and acclimatization steps. 'Bacterization' of micropropagated plants enhanced *ex vitro* rooting of tissue derived plantlets and supported better plant health in different crops (Nowak and Shulaev, 2003; Herman, 2004). Effect of bacterization before or during acclimatization can be sustained during field planting and growth to achieve robust growth and yielding capacity of micropropagated plants (Orlikowska *et al.* 2017).

viii) Plant tissue cultures – a tool for sourcing endophytic microorganisms

Plant tissue cultures system could be a potential tool to maintain and harvest beneficial endophytic micro organisms. A wide array of endophytic bacteria have been reported from horticultural crops such as banana, grape, papaya and watermelon that are commonly under micropropagation (Thomas *et al.* 2008a, 2008b; Thomas 2010, 2011 (not in reference). It is proposed that such systems can be useful to source these organisms for various benevolent applications.

Endophyte research and Socio-economic impact

With overpowering pressures from increasing population needing to be fed from diminishing cultivable land and lower input resources and imminent climate change, it is imperative to consider utilising microorganisms in improving agri/horticultural production to meet the food and nutritional needs.

In view of this, the intimately plant-associated endophytic microorganisms assume a greater significance if beneficial agents with significant plant growth promotion effects or mitigation of biotic and abiotic stresses are identified. Besides the direct benefit on plant growth or improved plant health, they may also reduce cost on inputs such as nitrogenous fertilizers or expensive plant protection chemicals. The novel invaluable biomolecules from plants that are perhaps due to the endophytic microorganisms, at least in a few known instances, would offer scope for treating dreaded diseases such as diabetes and cancer. The socio-economic impact would depend on the understanding of the plant endophyte interactions, the symbiotic processes involved in the metabolite production and ability to culture the organisms for which accelerated research in this emerging area of plant biology is advocated.

Conclusions

Endophytic microorganisms, prominently fungal or bacterial organisms, are found in almost all living plant species explored so far. They include cultivable and non-cultivable organisms, which perhaps form a mutualistic association with the host-plants.

Many fungal endophytes produce secondary metabolites and phytohormones (auxins, cytokinins, gibberellin, ethylene) that may help in growth and development of the host plant. The ability to colonize the internal tissues makes them valuable for various future research in a wide variety of research fields. There are great prospects for extensive utilisation of endophytic beneficial organisms in agriculture and allied sectors.

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Rethinking ownership of genetically modified seeds

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Abstract: Ownership is an important tenant of societies; it can be studied as a legal notion, a psychological one, or an anthropological one. In the context of new technological developments, ownership becomes important in terms of determining access, and sharing benefits and responsibilities. In the recent years, field of ethics for technology and notion of moral responsibility for risks have developed rapidly. When one considers use of biotechnology in agriculture, two main debates stand out—concerning risks and ownerships. This paper discusses a new way to conceive ownership anchored on ethics of technology and on practical philosophy literature, and points out moral responsibility of owners for stopping uncertain risks of genetically modified (GM) seeds. Doing so would allow an understanding of different narratives around GM seeds and would pinpoint observations morally desirable when risks are to be dealt with.

Keywords: Risks, Ownership, Genetically Modified Seeds, Experimentation, Rights

Ownership is an important tenant of societies; it can be studied as a legal notion, a psychological one, or an anthropological one. In the context of new technological developments, ownership becomes important in terms of determining access, and sharing benefits and responsibilities. In the recent years, field of ethics for technology and notion of moral responsibility for risks have developed rapidly. When one considers use of biotechnology in agriculture, two main debates stand out-concerning risks and ownership. This paper discusses a new way to conceive ownership anchored on ethics of technology and on practical philosophy literature, and points out moral responsibility of owners for stopping uncertain risks of genetically modified (GM) seeds. Doing so would allow understanding of different narratives

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around GM seeds and would pinpoint observations morally desirable when risks are to be dealt with.

Experimenting with GM Seeds

Debates around genetically modified seeds have been taking place for more than a decade (Wynne, 2001), yet they seem far from being resolved. Controversies live on, and might be reignited with the advent of gene editing and new breeding techniques. This enduring controversy has created a rift in regulations, for instance between the US and the European Union (Ramjoué, 2007). This had implications in the developments of GM seeds—for instance, strict European regulations drove some agro-chemical companies to move their research and development outside the Europe (Laursen, 2012).

While GM seeds can pass through the existing regulatory risk assessments of many countries, but their focus often is on the technical aspects of assessments. Uncertain risks, including societal risks, are not always addressed in assessments. Regulations can, therefore, be considered a field of experimentation (Millo and Lezaun 2006; Levidow and Carr 2007), as dealing with uncertain risks is a challenge to regulatory institutions (van Asselt and Vos, 2008).

Possible approaches to deal with the risks are: cost: benefit analyses, precautionary principle, and labelling (Thompson, 2007). For each of these approaches, objections can be voiced. Cost-benefit analyses deal with known risks only; the precautionary principle presents multiple interpretations (Sunstein, 2003) and labelling is problematic when one considers asymmetries found in the situations of informed consent (Spruit *et al.,* 2016). Adaptive management and participatory technology assessment are other ways of dealing with uncertainties but they have their own limitations (Robaey and Simons, 2015).

In the world's recent history with new technologies, There are examples of Beck's 'Risk Society' (1992), where new technologies had major unintended negative impact such as Fukushima. Engineering decisions create socio-technical systems, of which possible consequences are not always easy to predict.

Just as the ethics brought positive change to the practice of medicine after the horror of the World War II, they can also provide a constructive framework for dealing with the introduction of new technologies in the society, which can benefit the society, such as GM seeds; but at the same time can bring in much controversy because of uncertain risks. Just as ethics brought a notion of professional responsibility to the medical world, the ethics of engineering brings in opportunities to define responsibility for a complex socio-technical system, such as the one of GM seeds.

Before continuing with the next section, it is worth noting what can be considered as uncertain risks of GM seeds. It is fair to say that according to the most risk assessments, GMOs are not risky. It is also fair to say that agriculture, no matter which technology it employs, is experimental when it comes to taming nature. The question is how we choose to tame life and how much we would know about it in the long run. This is one of the streams of argument where civil society opposes GM seeds by. Another stream of argument is how this choice of technology would affect the way our society is organized, shares benefits and risks and changes farming practices. It seems that while innovations in biotechnology are fast moving, social and legal innovations are moving comparatively slower. The current system creates a lot of discontent as is seen by the civil society resistance and scepticism (for example see ETC 2014). So when referring to uncertain risks of GM seeds in this paper, they encompass natural and physical as well as social, economical and cultural events.

Who is responsible for GM seeds?

Recent developments in the field of ethics for technology can shed some light on how this responsibility can be implemented. Van de Poel (2013, 2016) has suggested looking at the introduction of new technologies as a social experiment, with the idea that by slowly scaling up, there is time to learn about new technology in its context and to adjust to different mechanisms. Typically, new technologies with great potential benefits and also with great potential consequences are subject to this framework, such as GM seeds. Van de Poel has suggested a set of conditions that make such a social experiment morally responsible.

One of the conditions for responsible experimentation according to van de Poel (2013, 2016) is the fair distribution of risks and benefits. In this paper, the focus is on the distribution of risks and uncertain risks. However, uncertain risks and known risks cannot be distributed but benefits can be. Uncertain risks and known risks are bound to a certain time and a place of occurrence. What can be distributed, however, are moral responsibilities to different actors involved in the social experiment – the ones who take the risks. The distribution of uncertain risks can be rephrased as the distribution of moral responsibilities for uncertain risks.

Who are the ones who take risks? The typical journey of a GM seed is as follows:- 1) research and development in a laboratory in the private sector, or at a university, 2) securing intellectual property rights on the GM seed (for instance see Jefferson *et al*., 2015 on how patents play out in agriculture), 3) go through a regulatory process, including a risk assessment, 4) commercialization to farmers, and 5) harvest and distribution. So in a way, all these actors share risk-taking by participating in the social experiment, as defined by Van de Poel.

The social experiment, however, begins most of the time in a private realm. The protection of GM seeds through patents is typically seen as a drive for innovation. In addition, patents are a legal instrument used to control distribution of economic benefits. This is especially true for GM seeds. Indeed, Buttel and Belsky pointed out that "Intellectual property statutes enable an individual seed company to develop new knowledge and products that can be denied to competitors. Thus, a seed company will have a greater incentive to develop new plant varieties than would otherwise be the case if there were no intellectual property restrictions" (p.32, 1987). Objections are since then found in the literature (*see* for instance Timmerman, 2015). Buttel and Belsky also underlined that commercial and private nature of this enterprise requires ethical and socio-economic assessment. At present, such assessment is not implemented in a way that would bear impact on the society. Baumgartner (2006) argued that, in the European context, the ethical concerns only look at the invention itself, and not at the invention in its context. So the patent application does not take into account how farming is organized, how benefits and risks are shared, and how an invention may change farming practices.

So it seems that of all the people involved in the journey of a GM seed, starting with those who control distribution of benefits is a good way to start investigating distribution of moral responsibilities for uncertain risks. This does not exclude other actors such as regulators or citizens from further analysis, but for the scope of this paper, the focus is on every owners.

Owning GM seeds

Before continuing, let it be clear that what this paper means regarding ownership and what the ownership is on exactly.

In *Notes and Queries on Anthropology* ownership is defined as the "sum total of rights which various persons or groups of persons have over things; the things thus owned are property" (1967, 148-9). This is a constructive notion of ownership. Legal scholar Honoré, describes ownership in a similar way, as a bundle of rights. Honoré (1961) presents ownership as a bundle of rights, with a list going from the 'right to income' to the 'right to exclude'. An important element of Honoré's approach is split ownership; how one object and its copies can be owned to different extents. So owner A might have all the rights on an artefact, and owner B might only have a few of the rights, and some of the rights might be shared, like the right to use. Together, owner A and owner B have a split ownership on the artefact. More specifically, if one of the rights of owner A was the right to lease to owner B, then owner B would have the right to use, and to have income from use perhaps, but no other rights such as exclusion. In this paper, an owner is, therefore, any person granted certain rights on the seed. Understanding ownership in a broader sense than that of patents allows conceiving ownership as a relation between people and things.

To summarize: the focus is on owners because owners are risk-takers (and benefits winners). Considering ownership only as patents is limiting when thinking of distributing moral responsibilities, so a constructive understanding of ownership has been taken, which allows broader analysis.

What do owners own then? In the case of a patent, this is clearly defined: a certain process and its outcomes are owned. If the notion of ownership is broadened, what is owned precisely? Koepsell (2009) uses the type/token distinction from philosophy of language and extends it to human genes. He explains that the type is an original idea, and that tokens of a type are physical reproductions of the type. For instance, the story and the words *Harry Potter* is a type, and every printed book of *Harry Potter* is a token. Extending this analysis to the case of seeds means that the idea of a new seed with particular properties (like the story) and the process to get there (like the words) are the type and the physical results, the GM seeds (like the books) are the tokens. The analysis of distributing moral responsibility for owners is, therefore, applied to tokens, i.e. the GM seeds.

With these distinctions in mind, the following section presents a proposal for understanding moral responsibility of owners for GM seeds in the social experiment.

Moral responsibility of owners

In the field of ethics, this is a remarkably under-developed topic of research. The following framework is a moral one, and not a legal one. Elements of this moral framework may be under implementation in the existing regulations around the world. There is thus a level of abstraction required from the reader. These moral considerations would be put in context in the next section.

Honoré speaks of a 'duty to do no harm' as one of the elements to a bundle of property rights (Honoré, 1961). Duties are a form of forward-looking moral responsibility, meaning a responsibility for potential harms, which have not yet happened, or in other words a responsibility to see to it that a certain state of affairs happens. This contrasts with backward-looking moral responsibility, which aims to establish blame or praise for an event that has already happened (van de Poel *et al.* 2015); this is not the focus of this paper. According to Goodin (1986), a duty prescribes a specific action to a specific agent (or owner) for a specific goal. This seems appropriate for dealing with known risks, as in, an agent A (or owner) should do X to prevent *i*. Earlier in this text, our attention was brought to uncertain risks, which were also the object of controversy. The notion of duty is insufficient to deal with uncertain risks, since it is unclear what an agent (or owner) A should do to prevent an uncertain-*i*. Using Goodin's (1986) definition of responsibility becomes relevant to this framework. Indeed, if the desired goal is *y*, where *y* is an open state of affairs where no harm is done. So owners also have a responsibility to do no harm. Then an agent A (or owner) must be able to learn about a situation to react and decide on how best to reach *y*. The way how to do this remains onthe discretion of the agent (or owner). In other words, to be responsible, an owner needs to learn to be able to decide on what actions should betaken to reach desired consequences.

When planting a new seed, owners need to learn about its impact, and observe what changes are occurring in a natural way and also in a social way. This would allow identifying where unintended and undesirable outcomes may arise. In turn, this would allow taking necessary actions to maximize positive outcomes from their use and minimize the negative ones.

Owners have moral responsibility for desirable outcomes from the use of seeds, and they must learn about it. One way to understand the idea of learning in ethics is to speak of the development of epistemic virtues, i.e. the character traits that would make someone a good learner. Examples of these traits or virtues are impartiality, intellectual courage and community (Montmarquet, 1987). In this framework, moral responsibility can, therefore, be understood at the moral responsibility to cultivate epistemic virtues.

Using this definition has two advantages. First, it does not limit moral responsibility to what is known already, but it expands moral responsibility for what remains to be known. Second, given that virtues are at the individual level, they also embrace the context of the individual. For instance, intellectual courage would not result same actions for a scientist or for a farmer, but both can develop this virtue. Through this, cultivating virtues allow owners to defining a range of actions they can learn about the GM seed being developed or used.

There remains one important question: if ownership is something that can be acquired and transferred, how can responsibilities be acquired and transferred? In other works, a detailed account of what makesup a good transfer of moral responsibilities has been presented by Robaey (2016b). For the purpose of this paper, the focus shall be on the main ingredient of a desirable transfer of moral responsibility: epistemic access, or the access to knowledge about the technology. To be responsible experimenting owners, having access to knowledge about the GM seed is important. This includes capacity to change it and to communicate it with other owners about the new knowledge acquired. This also includes cooperation among different owners —the ones who do research and development, the ones who commercialize the seed, and the ones who use it, the farmers. Here cooperation suggests that owners with more capacity to learn should support other owners in their learning.

All in all, having access to knowledge, and being able to develop one's knowledge is an essential condition to being responsible for GM seeds.

Many possible narratives for genetic modifications

In this paper, rethinking has been suggested on the idea of ownership for GM seeds, from a moral perspective. A set of ideas has been presented to apply to all GM seeds, keeping in mind that not all GM seeds are equal in their risk, social and environmental assessments. Each type of modification on seeds deserves an assessment of its own. The proposed framework does not have concern for this assessment, rather, it is concerned with how responsibilities can be discussed and distributed for GM seeds; given their uncertain risks. The proposed framework suggests that access to knowledge and cooperation are primordial to a desirable introduction of GM seeds. This framework was developed looking for a constructive way to discuss use of GM seeds to move beyond the usual stalemates. What such a framework suggests, practically, is that owners, regulators and citizens can make different decisions.

The cases that triggered reflection on this framework are for instance the one of Monsanto Canada vs. Percy Schmeiser. After this framework was developed, the case of *Bt* Brinjal in Bangladesh became internationally more prominent. These two stories offer an interesting reflection on choices to be made—both cases feature GM seeds but the conditions in which responsibilities and benefits are shared differ tremendously. Let us compare the two narratives[1] around the use of genetic modification in agriculture: Bt Brinjal in Bangladesh and Round-Up Ready Canola in Canada (the case of the lawsuit Monsanto Canada vs Percy Schmeiser). Considering these two cases show how socio-technical systems around GM seeds can be conceived of differently.

Almost two decades ago, the case of Round-Up Canola in Canada made headlines because a Canadian farmer Percy Schmeiser was replanting Round-Up Canola seeds harvested from his field, which he claimed he was not aware of. This resulted in a patent infringement case for the company who owned Round-Up Canola, Monsanto. A few years later, this was also settled in court as a case of contamination where Monsanto paid fees to clean- up the field of Percy Schmeiser. Here, the issue of ownership was determined by the law and by the courts. Percy Schmeiser claimed he did not know about the Round-Up ready seeds in his field. This was largely discredited during the lawsuit by prosecution.

Here, the notion of ownership is limited to the company owning the patent. What we can learn from this is that if the owner had a responsibility to avoid harm, measures would have been taken to prevent contamination. The later lawsuit showed that there was a measure of blame for the contamination as Monsanto had to bear the costs. This case has also given a clearer meaning to the idea of uncertain risks. Who was to know that Percy Schmeiser's field would be contaminated? The costs of the lawsuit, the clean-up, loss of trust in a company and its seeds were all unintended and undesirable harms resulted from the use of a GM seed.

Had there been a different set- up in the distribution of rights and responsibilities, these costs might have been avoided.

Let us now come to more recent times, and to another part of the world to look at *Bt* Brinjal. *Bt* Brinjal is a modified eggplant in which farmer has to use less pesticides as plant itself contains a gene that when expressed, targets specific pests. In 2013, four varieties of *Bt* Brinjal were approved in Bangladesh and were given to 20 farmers (out of 150,000 brinjal farmers in Bangladesh) in four regions with a total of two hectares of the crop (out of 50,000 hectares of brinjal in Bangladesh) (Choudary *et al.* 2014).The Bt technology was donated to the Bangladesh Agricultural Research Institute (BARI) by the Indian biotechnology company Mahyco and the transfer was supported by the USAID and Cornell University (ibid.). The Mahyco has entered a joint venture with Monsanto for *Bt* cotton more than 20 years ago.

Who is an owner? Part of what makes the case unusual is that here GM seeds are indeed owned by multiple actors at the same time, and without the patent controversy as the *Bt* technology was donated to a public research institute, and the seeds were given to farmers. According to a journalistic account of the case (Boersma *et al.,* 2017), farmer can keep and re-use seeds, may be even continue breeding them.

How is the responsibility to do no harm shared? According to Choudary *et al.* (2014), the condition for the release of *Bt* Brinjal stipulates training of farmers in terms of biosafety and the use of several other biosafety measures. The journalistic account (Boersma *et al.* 2017) indicates how small resource farmers who normally hand-sprayed their fields with pesticides were able to reduce use of pesticides on *Bt* Brinjal.The BARI is also setting up biosafety plan and organizing measures and monitoring. It seems that from a regulatory perspective, responsibility is distributed. Also farmers reported to have visited BARI several times (Choudary *et al.* 2014). From these first impressions, it seems that the way Bangladesh introduced *Bt* Brinjal, meets many of the requirements of the above framework.

Of course, similar tests, training and scaling up have taken place in Canada also. The difference is who owns GM seeds and this has implications for potential harms at a social and an economical level.

While Bt Brinjal remains controversial[1], it shows another kind of set -up for using GM seeds, where the focus is not on the patent infringements, but rather on a continued collaborative development of seeds between researchers and farmers, without barriers on access to seeds.

Conclusion

To conclude, I would like to refer to Asveld's framework on governing by experimentation (2016) where she argues that three types of learning have to happen. Learning about impacts, which involve monitoring and learning about positive and negative impacts. Institutional learning involves setting use of a technology into a broader societal goal and seeing how this or other technologies may help reaching that goal. This can also involve hearing and integrating dissenting voices, and considering alternatives. And last but not the least, there needs to be a moral learning about what values are behind their project and how these are justified, and perhaps how these might involve trade-offs.

How we conceive ownership, where we put priorities in the development of our seeds, and how we understand moral responsibility is an issue that pertains to all three types of learnings. Considering the cases of Canada and Bangladesh, it can be observed that making decisions on these institutional issues can greatly influence governance of GM seeds.

Note: It is important to note that all the information provided is from desk research only and is in no way representative of empirical work on the field.

Endnote

[1] A first controversy is one of biopiracy in India (Abdelgawad, 2012), another one is on the involvement of foreign actors such as the USAID and Cornell University in Bangladesh and a last one revolves around the proper identification of risks (GM Watch, 2016). Some recurring themes appear in these controversies: ownership and risks.

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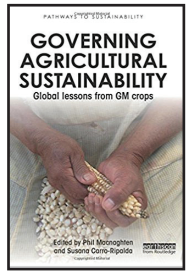
Book Review

Governing Agricultural Sustainability – Global lessons from GM crops



Editors: Phil Macnaghten and Susana Carro-Ripalda
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Use of biotechnology is considered important to express novel traits for crop improvement by their advocates, and they value it as a key component for the future of the world agriculture. Growth and maturation of biotechnology is most evident in the countries of the North, but its span and reach in the globalized economy has also permeated it into developing countries. Many claims either positive or negative of agronomic, environmental, health, social, and economic effects of the existing genetically modified (GM) crops have been put forth. There has been a highly polarized public as well as scientific debate on the agricultural biotechnology and development, specifically on its role in reduction of poverty and hunger. It has been characterized primarily by two contrasting views—an unqualified acceptance of the agro-industrial biotechnology developments in the name of the progress and free market, and of complete rejection as a form of (self) protection.

A diversion from above approach, this publication Governing Agricultural Sustainability – Global lessons from GM crops, edited by Phil Macnaghten and Susana Carro-Ripalda, focuses on what kind of politics is needed to accommodate GM agriculture on a global scale. Rather than merely delving into pros and cons of genetically modified crops, the book reflects on how and under what conditions genetically modified crops should be widely accepted and be qualified as for global public good. The wide-ranging information indicates a new approach to understand controversy on GM crops in relation to sustainable agriculture in future. Drawing on the extensive scholarship at the intersection of technological advance, globalization, political and economic power and cultural identity, the book presents an alternative pluralistic and inclusive model for decision-making – a model that just might move us towards better governance of technological change. Responding to the challenge of agricultural sustainability, this book offers a new pathway for governing GM crops through the recent debates on responsible innovation, agricultural sustainability and on social justice.

The book is in two parts with 17 contributions. Part 1 draws on the empirical research undertaken in Brazil, India and Mexico – exploring views of scientists, farmers and public. Using a diverse array of ethnographic and qualitative methodologies, it examines dynamics that underpins controversy in three diverse geo-political contexts — the manner in which dominant institutional framing has closely been aligned with the interest of powerful elites; multiple ways in which these have been resisted through local, symbolic and material practices. Part 2 comprises a series of short pieces from 11 leading academics in social and life sciences; responding to the question of how to develop a policy framework for responsible innovation of sustainable, culturally appropriate and socially just agricultural GM technologies.

The book, which can be easily understood even by those without any specialised knowledge about GM crops, gives valuable insight on governance of emerging technologies in a responsible manner. The Chapter 1 sets out the context and the conceptual approach, which is informed by debates in five intersecting literatures: on science and publics; on extant analyses of the GM controversy; on emerging frameworks on responsible innovation; on literatures on pathways to sustainability; and on culture and forms of life. Chapter 2, 3 and 4 review trajectory of debate and also on controversy over GM crops in Mexico, Brazil and India. Rich empirical ethnographic research with farmers, scientists and public in these countries bring different voices to the fore; the authors reiterate how technologies are framed differently in different settings.

In the Mexican case, the prospect of GM maize is seen by smallholder farmers as an intrusion on the traditional practices. The scientific community views are divided on the use of genetically modification technologies on maize genome and the urban public, in general, has a negative reaction to GM crops and foods. Further, there has been little sustained effort by the state to engage the public. In the Brazilian case, presented in

Chapter 3, scientists are optimistic about the role of GM crop technologies; they emphasize national benefits and necessity for agricultural GM research for a strong national base. The urban public was either ignorant or to had little knowledge or awareness on GM crops and foods, and were genuinely surprised about the extent of their adoption. Although there is a trust in the expert systems, the Brazilian public, however, adopted a negative opinion on GM crops and foods as the technology was perceived to benefit the producer (not the consumer) and it was felt that the public was not adequately consulted or clearly informed. The conflict between farmers and technical experts from seed companies was clearly evident to authors; each blaming the other for growing problem of weed resistance to glyphosate. Chapter 4 identifies trajectory of GM debate in India and highlights factors leading to ongoing resistance to GM crops in the country, culminating in 2013 ten-year moratorium. The authors find a general sense of optimism among wider scientific establishments and central government towards GM crop technologies with a few voices raising concerns about its techno- economic and ecological implications. Civil societies are observed to be spearheading articulation for these concerns in the Indian case. On Indian public responses, the authors noted urban public projection of negative views on GM crops and foods, reflecting mistrust in the government and local authorities in providing a reliable regulatory system for production of GM crops.

The Last Chapter of Part I compares responses to GM crops in Mexico, Brazil and India. A pattern of overlaps but on important specificities was observed in the chapter. Across three nations, the author indicated that the national regulatory bodies and technical committees setup to regulate GM crops, even though they included representatives from leading public universities and research institutes and were situated within a complex network of variously configured inter-ministerial responsibilities and obligation, had not provided 'authoritative governance' in terms of taking decision, developed through transparent deliberations. In terms of explaining different trajectories that GM crops has taken in these countries, the author identifies different factors to be relevant in structuring controversy viz. the perceived authority of the regulatory agencies, the cultural resonance of the crops in question, the level of intensity of protest movements, the extent to which GM can become a represented symbol of wider struggle, and the degree of sustained effort by institutional actors to engage the public. Comparing the laboratory ethnographies, the research culture of the laboratories across the three sites was observed lacking in two of the core dimensions of a responsible governance framework - 'reflexivity' and 'inclusiveness'.

The second part of the book opens up debate on the governance of GM crops through a set of commentaries spread across 11 chapters (chapter number 6-16). Chapter 6 reflects on the GMFuturos study as a valuable attempt in widening debate on crop genetic engineering technology moving away from risks to impacts on people's livelihoods, societal values and sanctity of traditions. The next chapter compares cases of Mexico, Brazil and India with those of China, taking into account the specificities of China's dynamic governance context. Chapter 8 justifies narratives on the adoption of GM crops in 'rising power' settings to test, using an innovative combination of social science research methods. The idea of 'stewardship' is put forward as an integral element of the framework of responsible innovation. Chapter 9 develops a non-reductionist account of GM crop technologies emphasizing on multiple ways in which GM crops are enmeshed in culture and societal aspiration. The commentary in Chapter 10 draws lessons on the need to frame public responses within their political-economic contexts, and demonstrates how a biotechnological vision of further industrializing European agriculture was promoted as an overall solution to the problem of European competitiveness. The science of genetic modification is contextualized in Chapter 11 and the role of theology as offering narrative resources to reconfigure the governance debate on GM crops is reflected in Chapter 12. Further, Chapter 13 contextualizes findings of the GMFuturos study within a broader narrative of disconnect between agricultural science and everyday food practices. Chapter 14 reflects on the power of context and the threat to fundamental values in determining responses to risks; highlighting need for longitudinal studies and potentials of emerging policy frameworks of responsible innovation. Chapter 15 deliberates on the institutional rigidities and impediments in the Indian agricultural science and technology system that continues to resist learning against possibility of more responsive and deliberative alternatives. The commentary in Chapter 16 emphasizes on the use of focus groups in helping open- up new kind of debate, deliberation and participation.

Drawing on the insights from the eleven commentaries, the last chapter of the book discusses on the application of a responsible innovation framework to the governance of GM crops as a pathway to sustainable agriculture and as a response to current institutional void. It is argued that responsible innovation framework is needed to move beyond sterile arguments of being proponents or opponents of the technology or confining merely to issues pertaining to risks and benefits of the technology.

This book departs from a dominant science-centric and techno-centric view of the crop genetic engineering, which vests too much autonomy and power to the physical technology itself as the driving force of technology diffusion, ignoring social contexts, the relevant social groups and the institutional factors involved and which enable (or constrain) innovation. Technology evolution and innovation is generally too complex to be adequately understood from a context independent perspective. This edited but integrated volume provides a novel comparative analysis on the social, cultural and political factors explaining why controversy surrounding GM crops has taken a variety of forms in different national settings. This book encourages richly textured descriptions and analysis of the relevant contexts at play in development and deployment of GM crops in a wide variety of different agro-ecosystems and countries. It gives readers concerns about public controversies surrounding emerging technologies, and the occasion to think about better governance of technological change. On the narrower side, more can be done to reflect on and revise agricultural biotechnology governance in the wake of a new wave of genomic tools and products (beyond GM crops), which would supposedly revolutionize biotechnology by allowing easy, cheap, precise and predictable genetic modification. Further, as a potentially valuable avenue for additional probing, an exploration of the ambit of regulatory frameworks and the existing definition of GM organisms would highlight the uncertainty that exists with respect to these new genomic tools and products and techniques. This would help stimulate further debate and action towards improved form of governance, particularly, as future emerging genomic tools and products continue to unfold.

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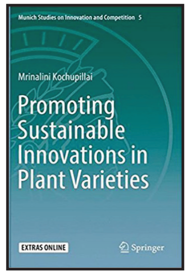
Book Review



Promoting Sustainable Innovations in Plant Varieties

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Plant varieties are the genetic vehicles of crop species that enable crop productivity for food and fodder. The cassette of genetic information that prevail upon the performance of crop varieties for high yield, tolerance to various stresses as well as the preparedness for surviving aberrant weather patterns is developed through innovation. Plant breeding for improvement of crop traits has evolved from the farmers' efforts to the highly focussed efforts of the research scientists. The narration in the book by Dr Mrinalini Kochupillai develops around her doctoral research to study the facets of developing plant varieties through innovation. The perspective whether farmers own seeds have novelty in traits, distinctiveness and uniformity vis-à-vis that from plant breeders of the public institutions or from private seed companies is exhaustively discussed. Dr Mrinalini Kochupillai succinctly raises the arguments on the sustainability of crop plant varieties and agriculture based on her doctoral work including field studies in the context of Indian agriculture. Spread over seven chapters with useful seven annexure and robust bibliography, the book narrates the socio-economic panorama of sustainable innovation in the development of crop varieties at farmers' innovation level and that of seed industry.

The author adopted a multi-disciplinary approach in order to suggest means of promoting 'sustainable innovation'. Accordingly, a mixed methods approach comprising an exploratory approach, based primarily on qualitative analysis and a confirmatory approach, based on quantitative analysis, was selected to answer several hypotheses and research questions. The dominant design for the qualitative segment of this research was the historical method coupled with conventional legal research using the tools of literature review and legal interpretation and critique (e.g. of statutory provisions and decided case law). The dominant design for the quantitative segment was the collection and statistical/econometric analysis of non-experimental data, including available data on plant variety application trends and survey data.

The introductory chapter provides for an analysis of the philosophical and economic justifications of 'sustainable innovation'. The author dwelt deep into the Schumpeter's 'Creative Destruction' (as appeared in '*Capitalism, socialism and democracy'.*), the destruction may or may not be complete and permanent—there is always a possibility that the old re-appears, perhaps in an improved version or by virtue of its antique value. In Schumpeterian 'Creative Destruction,' therefore, while there is no forced destruction of the less desirable, there is nonetheless, a possibility that the old is completely destroyed, *inter alia*, due to obsolescence. 'Sustainable innovation' in plant varieties is accordingly defined in this book as the parallel promotion of both *in situ* agro biodiversity conservation and innovation in the form of crop improvement by both farmers (informal sector) and breeders (formal sector). The terms 'rural innovations', 'informal innovations' and 'farmer level innovations' in relation to seeds are used inter-changeably in this book. They refer to improvements and/or *in situ* evolution of seeds resulting from initiatives of individual farmers or farmer collectives without any intervention or support from the formal sector (i.e. the private or government sector plant breeders). The significance of conservation of crop genetic materials by farmers and communities fades out when old varieties are replaced with new ones.

The author develops strong parallel between Sombart and Schumpeter in elucidating the 'driving forces of transformation' and creative destruction. Innovations as drivers of capitalism for developing their ownership are prominent in the work of these authors. The farmers innovate to select plant types of crops from available land races that have specific advantages of yield, resistance to prevailing agro-ecology and weather situations and with specific quality of the commodity. The evolutionary origin of land races as genetic cassettes of crop genetics has resulted in the utilisation by human beings into cultivable crop varieties by selecting and inbreeding them to create uniform agronomic characters. These selections are shared amongst communities and villages that become traditional crop varieties in large scale cultivation. In order to efficiently utilise such traits, modern plant breeding utilised higher level scientific tools and techniques to utilise these genetic traits and created open pollinated crop varieties and hybrids, as the case may be. While doing so, the author expresses reservation on the sustainability of traditional genetic make-up and traits and hence the Schumpeter theory of destructive creation is bought in.

The chapter 2 explains the notion of 'sustainable innovation' from an international legal perspective by providing an overview of the international legal framework within which plant variety protection laws and agro biodiversity protection laws, are contextualized today. The chapter also explains the motive behind the coining of the term 'sustainable innovation' and why a specific definition was assigned to the term.

The issue of sustainable innovation from a scientific and ecological perspective has been discussed in Chapter 3 by describing the traditional and modern methods used for crop improvement. Socio-cultural factors that affect and are affected by formal and informal/traditional seed improvement methods are also discussed in this chapter. It also delves into the economics of plant breeding associated with the direction in which modern plant breeding technologies are headed.

The next chapter 4 describes and analyzes the Indian agricultural sector and plant variety protection regime via the evolution of Indian national agricultural policies, recent case law, case studies and plant variety application trends. The discussions in the chapter identify a paradox in the laws and policies relating to plant varieties in India, and by extension, in any other country that seeks to simultaneously promote both *in situ* conservation of agro-biodiversity and formal innovations in plant varieties: laws that promote the latter appear to undermine or dilute the impact of laws and policies designed to promote the former, and vice versa.

Chapter 5 provides the details of the findings and conclusions drawn from the statistical analysis of the data collected via farmer surveys in India, including the method adopted for coding and analyzing the data, which helped confirm or tentatively reject the hypotheses emerging from the literature review and the qualitative research presented in the previous chapters.

Chapter 6 takes another look at Schumpeter's theory and definition of innovation and its relationship with modern intellectual property laws. It identifies (a) the specific market failures that plague the present day plant breeding/innovations sector and (b) an anomaly in the structure of intellectual property protection regimes (particularly patents and the plant variety protection regime under UPOV 1991) that interferes with their ability to address these market failures and promote 'sustainable innovations' in plant varieties.

Accordingly, the chapter 7 which enumerates a set of recommendations, concludes by suggesting that regimes beyond those designed to protect intellectual property rights would likely be necessary to promote 'sustainable innovation' in plant varieties in general, and *in situ* conservation of agro biodiversity in particular.

In the plant breeding, unlike in any other industry, the conservation and natural evolution of the 'old' is as important, if not more so, than the creation of new varieties. This is especially true because of the characteristics of the 'new' varieties: They not only are engineered to have severely limited genetic variability (making them unsuitable for marginal environments), but are also engineered to prevent *in situ* seed saving and seed improvement by farmers. The author develops this thought considering seed (plant breeding) industry as the major focus. In countries such as India, where the crop improvement has been entrusted to the public institutions from colonial times, the major crop varieties that farmers cultivated until the end of the last century was of public bred crop varieties. In the hope of exploiting hybrid vigour in crops such as rice, maize, sorghum and pearl millet as food crops and of cotton, research on hybrid vigour was intensified. Private entrepreneurships also developed for hybrid seed production of these crops. They blossomed into organised industries. In many other continents, private investment for crop improvement research and their hybrid seed production was strong. The principle for introduction of new crop varieties shall be based on the addition of new genetic traits to make the new one superior to the old one. The spectrum of the catalogued local land races that are located through plant genetic surveys may not be complete and would always have scope for addition with new, unique land races that are evolved to adapt to present agro-climate and ecology. The investment for this is the key to innovation in seed sector.

Another facet that the author builds around is the right of farmers' innovations and commercial intent of seed industries' innovations in utilising genetic traits of land races and such plant types of crops with large number of useful characteristics. So the traditional knowledge and associated genetic materials to enable new knowledge and products need due recognition. Considering such common persons as 'partners of capitalist stratum' that thrive on new crop varieties is the advocacy developed in this book. This partnership of the seed industry with local communities/farmers in utilising ITK of genetic information and land races is argued in this book as the 'partnership at capitalistic stratum' and a 'symbiosis of the seed industry with farmers'. It is further argued that this relationship is stronger when the farmers utilise the improved crop varieties / hybrids to gain better economic return from their farms. The institution of traditional innovation system is destroyed in this process and new institutional system of seed industry for crop seed development is created. It is argued that intellectual property laws and associated policies do not secure *in situ* seed conservation. The author fears that the 'technologies that are designed' for new varieties rule out the possibility of seed saving and improvement.

Seed replacement has been an approach to sustain crop productivity by ensuring genetic purity. The seed replacement ratio (SRR) has been good in cereals such as rice and wheat while in pulses it is not so commendable. The issue of SRR in pulses has been discussed. Pulses have the dubious distinction of being cropped in marginal lands under rainfed agro-ecologies. SRR is a recourse to reduce genetic erosion due to the continuous use of seeds derived out of continuous self pollination over several crop cycles. This is mainly applicable to open pollinated seeds. Farmers' own seeds suffer from genetic degeneration after few crop cycles if the fields have adjoining plots cultivating other varieties of the same crop. Crop hybrid seeds do not have this challenge since annually fresh F-1 seeds are sold for cultivation.

The research leads to the recommendation with arguments on the need for relook on UPOV agreement and Protection of Plant Varieties and Farmers' Rights Act, 2001 to attain and promote 'sustainable innovations' in plant varieties. The author emphasised the need for managing agro-biodiversity conservation and land races are highlighted as sustainable innovations in plant varieties. Both 'formal sector' of plant breeders (both public and private) and the 'informal sector' of the rural folks in farms facilitate this process.

This book hence has intense analysis of the plant breeding for crop improvement through social, economic, legal and political framework. The highlight of Indian context for this analysis has been duly supported by the field research.. It is also noteworthy that the findings of this book are not only relevant to biodiversity rich developing countries like India, but also to those countries that do not have much agrobiodiversity of their own, but rely on agro-biodiversity emerging from other countries, to make their own plant breeding industry or agricultural sector more innovative in the short and long run. This book can be a good read for researchers, policy makers, academicians, law practitioners and civil society representatives working in the related domain. The book price in India is on a bit higher side. Maybe, the publishers think of bringing out a cheaper edition in future for its wider dissemination.

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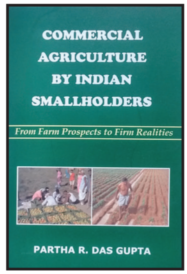
Book Review



Commercial Agriculture by Indian Smallholders – From Farm Prospects to Firm Realities

Author: Prof. Partha R. Das Gupta©
Publishers: Maya Publishers Pvt. Ltd., New Delhi-110012 & Samskriti, New Delhi-110070 in collaboration with Syngenta Foundation for Sustainable Agriculture, Basel, Switzerland
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When technology-driven agriculture is planted in the innovative minds of Indian smallholder farmers (from the states of Maharashtra, Odisha and West Bengal) innovation for local adoption and it would bring huge change in their existing farm economics. *Commercial Agriculture by Indian Smallholders – From Farm Prospects to Firm Realities* is the lucid narration by Prof. Partha R. Das Gupta of Syngenta Foundation for Sustainable Agriculture (SFSA), Basel, Switzerland (the Indian arm being not-for-profit institution Syngenta Foundation India (SFI) – established in 2005) about the potential to transform the livelihood prospects of smallholding farms in four locations of threes states into commercial farming for richer harvest.

There is the fast-fragmenting agricultural land holding of 1.16 ha as in 2010-11 NSSO data against 1.33 ha of 2006 census data, far below the cut off of 2 ha that is actually the small farm norm. The fragmentation of farm land limits farm families to secure income from farming alone. The challenge to revitalise the rainfed agriculture of small farm holdings was taken up by SFI. It prepared road map in which pilot scale projects were designed. The recent government policy announcement on 'doubling farmers' income matches well with the experiences provided in this book by the author.

The book narrates in the efforts of the SFI, in association with local civil society organisations to practice self-sustaining farming in Indian small holding farms. Through the pioneering pilot and subsequent full scale involvement at Anandwan / Somnath, Chandrapur (Vidarbha region of Maharashtra) as given in chapter 1; resurgence of agriculture in Jawhar

(Konkan, Maharashtra) in chapter 2; emergence of new Kalahandi (Odisha) in chapter 3 and small farmers make it big in Bankura (West Bengal) in in chapter 4, Prof. Das Gupta successfully brings out vividly the saga of the mission-oriented programme to revive the smallholding farm economy in the four agroclimatic situations. The concept of profitability from farming has been pursued by SFI through the high-tech and knowledge-driven farming practices.

Dr M.S. Swaminathan in his Foreward to the book states, "small farmers can take big steps forward" and this is exemplified in the book by Prof. Partha R. Das Gupta. As much as the villagers have mastered the technology of high speed motorbikes or cell phones in recent decades, their preparedness to imbibe high-tech farm technologies is epitomized in this book. The significant imagery on facilitation of the most essential agri-inputs, micro-finance and access to market is the pillar of success to such projects. The ecosystem that is woven out of the local resources has sustained the local partnerships between various actors who patronized the increased productivity of the farm commodities. The book narrates vividly the flow of money into farming families of the project villages across the country through the SFI initiative on intensive agriculture.

The selection of farm enterprises such as market-driven vegetable production, high quality hybrid seed production of rice and vegetables for making available local farmers, integration of livestock and fisheries in accordance with the resources of the villages have been masterly entwined in the plans and programmes for each of the four locations. Interesting hand-holding with organisations such as BAIF-SEDP could strengthen the goal of transformational paradigms in order to shift the present approach with futuristic innovative farming practices. Creditable SFI initiative was to organize farmers these technologies to imbibe the farm technology and knowledge along crop seasons. The farmers could absorb technologies and skills to build up confidence for plunging into the risk-bearing entrepreneurship such as for commercial hybrid seed production, high value vegetable production or pushing the high yielding vegetable production for small towns and urban markets. The vivid detailing of experimentation in the four locations to introduce concepts such as market-led extension of fruit-bearing technical knowledge and build-up of farmers' confidence to become entrepreneurial are the highlight of the narrative that signify the success of the SFI initiatives. The idea to move with the locally influential social organisations such as Late *Padma Vibhushan* Baba (Muralidhar Devidas) Amte's *Maharoga Sewa Samiti* at Warora (Maharashtra) and similar ones in the locations to get to the hearts of farming families along with carefully chosen project partners is professionally ingenuous.

Chapter 1 provides lucid narrative about the agriculture at the Dr. Baba Amte's Anandwan in Warora, Chandrapur district (Maharashtra) became an impetus gaining economic strength of the farmers of Anandwan and Somnath. The author gives anecdotal narrative to illustrate the catalytic efforts of technology interventions in reforming the prevailing practices to bring about the change in the profitability of farmers. Appropriate Technology interventions in rainfed farming of black alluvial soils of Vidarbha region is a tell-tale narrative in this book. The planned programmes that Baba Amte steers through with the help of SFI initiatives make Somnath village more prosperous. Technology driver in the ridge-furrow cultivation of Soyabean in Trupti Sadan, rice cultivation in Shanti Sadan, and hybrid brinjal cultivation at Phaal village made the smallholding farmers to achieve greater benefits and prospects. The trigger for the establishment of Agritech School at Anandwan in 2010 and its growth into the Agricultural Polytechnique under the Panjabrao Deshmukh Krish Vidya Peeth (PDKV), Akola is the best example that the SFI could initiate to enhance skill in the farming families of the region. Agri-business, seed production, animal husbandry and livestock management, fisheries and aquaculture, home science and post-harvest processing are part of its curriculum to make the farm youth independent and enterprising. Skilling of youth and developing women entrepreneurship in villages of the Chandrapur District is commendably achieved by this institution in the last seven years.

The Chapter 2 illustrates the hand holding with Pragati Pratishtan (Sunanda Patwardhan ji) to reform the farming practices of the tribal villages to make the farmers reap higher profit from the farm land. Introduction of technology transfer for 'System of Rice Intensification (SRI)', vegetable cultivation, intercropping vegetables in orchards, certified rice seed production and agro-forestry with cashew/mango fruit trees were undertaken in three phases. Hand holding with Bharat Agro-industries Foundation (BAIF) got a fillip to the tribal village progrmmes in vegetable cultivation. The author provides vivid and illustrative narrative about organising farmers for collective marketing through BAIF-affiliates such as Amrai Tribal MITTRA, Fruit Processing and Marketing Cooperative Society ('Amrai Coop'). 'From Thane to Thames' is anecdotal punchline in the narrative on pilot plan of export of vegetables from the SFI project area at Mokhada (vegetable valley) village in 2010 through the hand holding with a private exporter through contract farming on global GAP norms. From 35.6 ha in 2011-12, the vegetable area grew to 157.4 ha in 2014-15, mainly lured by the market linkage to produce over 2576 mt vegetables in that year's *kharif* season; all within the average holding size of 0.12 ha tribal area farms. This vegetable production hub emerged as major supplier to Mumbai and its suburbs. The critical mass for commercial vegetable production could be created in the Mokhada-Vikramgad project area. The average net income of the tribal farmers of the region in each kharif season from 0.12 ha land shot up to Rs 21000 that is 45% more than the labour wages earned by 100 days of work under 'Mahatma Gandhi National Rural Employment Guarantee Act'. Such incentives and smart options could make many tribal farms to produce vegetables in *rabi* season too using support irrigation. Ultimately migration of farm families to neighbourhood towns and Mumbai could be much restricted due to steady income from the land.

Chapter 3 is the SFI experience in the eastern India at Kalahandi district in Odisha. The extensive description in this chapter on programmes with the integration of organizations such as Kalahandi Association for Rural reconstruction and Total Awareness Benefit of Youth Action (KARTABYA) is a treatise to the emerging 'Start-Ups' in agricultural sector of the country. Good quality (genetically pure with high vigour) crop seeds being the primary input in farming, and farmers struggle to access this during each cropping season, SFI took up the mission on developing Seed hubs for hybrids of rice and vegetable crops. Alongside the mission on crop intensification for higher productivity and profitability from unit land, the technological interventions for SRI production and vegetable cultivation enhanced the scope to make smallholding farmers to be aspirants of profitability from a situation of bare livelihood from their agricultural land. Market-led extension as a strategy to transfer technology and knowledge worked well in Kalahandi, with its good natural resource potential. It shot into hybrid seed hub for rice and high value vegetables. The transformation of the project area into amazingly profit oriented agriculture is elaborated. Farmer to farmer seed movement was visualized when the high yield variety development programme in crops through ICAR-All India Coordinated Crop Improvement Projects were commenced. The SFI took on this mission earnestly and could succeed to convert ordinary farmers into vegetable growers and seed producers through smart networking as well as handholding of the farmers groups with knowledge-bearing team of extension workers of SFI. Ultimately, the seed companies found congenial system for organizing contract seed production of crops such as rice, maize and vegetables through the experienced seed producer farmers. The author's picturisation of the seed enterprise in 252 ha of 343 farmers with estimated value of seeds produced for about Rs 180 million is fascinating. Odisha government declared Rs 25000 per ha as subsidy for hybrid rice production farmers. Prosperity through smart agriculture could be enjoyed by Kalahandi farmers under SFI smallholder farmers' extension programme. The World Bank funded project: ICAR-National Agricultural Innovation project (NAIP) under Component 3 (Sustainable Rural Livelihood and Food security to rainfed farms in Orissa) had KARTABYA as consortium partner, as recommended by SFI. Similarly the partnership of SFI with 'Youth Council for Development Alternative (YCDA) for microfinancing for vegetable cultivation, '*PRADAN*' for livelihood security and women self-help groups and Association for human rights education and development (AHEAD) for growing pulses, maize and cotton in Naupada district (villages of the old Kalahandi district). The narrative in Chapter 4 is about the disadvantaged Bankura (West Bengal) district having drought in spite of 1340 mm rainfall and the SFI designing farm technology-loaded package of hybrid vegetables, hybrid rice and SRI, homestead goat farming, duck farming and fish farming. The strong association with the local organization, Shamyita Math became catalytic for developing agricultural advisory programme for the local farmers. The initiative to harvest rain water in the village-tanks to irrigate high value vegetables enhanced irrigation coverage to over 40%. Desilting and deepening of village tanks was fruitful to accelerate the adoption of vegetable cultivation in many villages. Participatory seed production plans were drawn for hybrid rice and branded as 'Sree Rohi seeds' could enhance the esteem and self- confidence of farmers of Bankura. With the hand-holding of local agricultural experts, the *Shyamita Krishi Kendra* (SKK) could become the farmers' resource centre for technical knowledge, farm implements such as *kono* weeders and high yielding crop seeds and other farm inputs. SKK became a two-way track for farmers to access technology and knowledge and SFI vehicle to ply through farming families offering various strategies to make their farm income improve steadily. Examples such as ‘hub and spoke’ market-linked intensive commercial vegetable cultivation, potato production linked to processing factories, SRI based hybrid rice cultivation, servicing of village water tanks for farming and homestead livestock / fisheries and goat rearing / piggery enterprises are described in the book as excellent success stories that got spread over to adjoining Purulia district too.

The author has successfully captured and encapsulated in this book the professional SFI programmes that were executed between 2004 and 2014. The goal of enhancing small farmers’ income through situation-specific appropriate farm technology for bettering crop yields, cropping intensity, commercial seed production, integrated farming system with homestead livestock and poultry, market-driven crop production, micro-finance set up and committed participation of local organizations for deep participation and facilitation. The spinoff from these four enduring examples of attempt to double farmers’ income in tune with government mission is the intense vocational training for farm youth and improving women power for timely farm-centric management decisions. The perceived risks in undertaking high value agriculture that became accepted practice in these projects were imaginatively mitigated through astute micro-finance institutions. Probably agricultural insurance could become a risk-proofing farm input for undertaking high-tech farming. The lucid reading of the book to get the feel of the ups and downs of every project significantly etches into the reader is the testimony to the author’s pain to make this book a free-flowing text with number of anecdotes. The book brings out the saga of bringing changes in farming through location-specific technology recipes in the phase I to phase III journey of the SIF programmes in all locations. The author has provided the panorama of the extension mechanisms and techniques adopted in each of the location where SFI took up knowledge intensive farming practices for changing livelihood pattern of the deprived smallholders.

The author may consider the analysis of nutritional satiation of the region through the introduction of dairy, fruits and vegetables in the cropping system in the course of the mission on crop intensification. Protein and mineral nutrition is best achieved to all members of families and could be to be valued and assessed while providing project achievements of locations. Economic valuation of satiated food, nutrition and health of farm families can be the indicators for such hard effort to make smallholding farms commercially viable. The sustenance of Indian agri-biodiversity is one of the key achievements of such projects. The effort to maintain and utilize these crop bioresources is indeed the hidden success to achieve the economic benefits of communities of the region. A value chains that are created through such projects need elaborate studies in terms of employment and income generation, social value chains, and *ex-ante* / *ex-post* socio-economic impact over decades. The project managers may have the opportunity to subject such project areas for follow up of the sustainability of these enterprise created. These could be good subjects for the local educational institutions to involve their students for training on dissertations. The silent transformation from 'livelihood farming' of the villagers in these states where the projects operated to 'commercial agriculture' has elements of emotions of people that keeps generations to remember the SFI programmes and continue them effectively through similar mentoring organisations.

One can deeply sense after reading this book that the systems pursued by SFI can be replicated through robust hand holding with small farmers in any state by similar goal-bearing individuals or institutions.

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This issue carries two articles and three book reviews. An article on endophytes discusses recent developments on studies onendophytes and how they can be utilized for different applications in agriculture. It also highlights the scope for biotechnological interventions in using them. The second articles analyzes ownership and responsibility in Genetically Modified Organisms (GMO) from a philosophical and ethical perspective. Three book reviews discuss inter alia, new approach to plant variety protection with a case study based on India, and, agricultural sustainability and GMOs.

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