Incentivizing & Promoting Sustainable Seed Innovations in India: A Three-Pronged Approach

Position Paper for the Government of India
Compiled with research support provided by the
UK Global Challenges Research Funds

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Executive Summary

Indian agriculture, for all its successes, has become imbalanced in favor of seeds engineered to produce high yields with help from expensive and environmentally damaging pesticides, fertilizers and other industrial inputs. Without seeking to replace the conventional farming system in India, this position paper proposes rebalancing Indian agriculture to give indigenous seeds, farmed using the best of traditional-ecological methods, new prominence. This proposal has been made with three primary goals in mind:

(i) expanding the role and contribution of small farmers in the Indian economy by helping them become “know-how providers and innovators,” rather than remaining mere “technology/innovation users”;
(ii) expanding the choices available to Indian farmers vis-à-vis systems and approaches to agriculture, in order to facilitate a shift towards more sustainable (eco-friendly) agriculture, keeping the interests of all stakeholders, as well as the need to ensure long term food and nutritional security, in mind, and
(iii) expanding and strengthening India’s organic and circular economy with the help of (i) and (ii) and making India a world leader in the supply of organic seed and food.

In order to accomplish these goals, the paper suggests interrelated action on three main fronts -- a "three-pronged approach" to incentivizing and promoting ‘sustainable seed innovations.’

First, the government should counteract the widespread impression that traditional ecological knowledge (TEK) is intrinsically inferior as a source of farming methods. On the contrary, TEK methods should be represented as not only good for the environment (e.g. by enriching rather than depleting soil microbial diversity; by recycling rather than increasing farm waste; etc.), but as exactly the methods that India's indigenous seeds, in all their amazing diversity, require to thrive. Further, the capacity that these farming systems give to small farmers to become innovators and know-how providers (rather than mere users of imported technologies and inputs) needs to be highlighted.

Second, the scientific education which farmers receive, formally and informally, directly and indirectly, should be overhauled to emphasize perspectives more conducive to their choosing to farm, and even innovate with, indigenous seeds and locally relevant farming systems. Instruction in genetics, for example, should go further in stressing the importance of environments in determining what the genes in seeds are "for," the better to ensure that farmers see their seed choices as always environmental choices too. Farmers might also usefully be taught about the sociology of innovation in science itself, where "intellectual property" (IP) has always meant more than just patents and copyright, and where a reliable system of public crediting of innovators has long been a major spur of advance.

Third, the government should take the lead in establishing just such a public crediting system for India's sustainable seed innovators. An especially promising means of doing so is adopting Digital Ledger Technologies (DLTs) such as blockchain, together with Artificial Intelligence (AI)/Machine Learning applications built thereon. These technologies can help ensure not only that innovative farmers or groups are publicly recognized for their work but that they are able to track and profit financially from downstream uses of their innovations. These technologies are being researched the world over, inter alia, for their capacity to better manage and monetize data, while giving the contributors of data greater control over its use. Indian farmers too, should be given means of accessing and using this technology to share and monetize their know-how vis-à-vis farming methods and indigenous seeds with the world, and bring economic as well as environmental gains to themselves and to their communities and country. In fact, these technologies can also support existing laws, particularly access and benefit sharing rules under the Biodiversity Act, accomplish their goals more smoothly, in the true spirit of their intent, for the mutual benefit of all stakeholders.

Further, in order to accomplish the above stated goals by implementing the three prongs, and in accordance with insights emerging from modern science, the government should revise or reconsider
certain existing as well as planned legislative provisions. For example, relaxing criteria on genetic purity and "uniformity" in the planned Seeds Act, expanding the benefit sharing provisions within the Protection of Plant Varieties and Farmers Rights Act (PPV & FR Act), 2001 to all instances where indigenous/heterogeneous seeds are used by the formal sector (and not just in cases where they are used in hybrid breeding programs or where the downstream results are protected by IP), supporting the move to bring digital (genetic) sequence information associated with biodiversity within the scope of the Nagoya Protocol (provided technical and user friendly systems such as those supported by DLT/Blockchain are adopted in parallel so that scientific research, and therefore innovation and value identification, does not suffer as a consequence) etc.

Finally, alongside activities on these three fronts, the government should invest in further multi-disciplinary and multi-stakeholder academic research which, by determining strengths and weaknesses in claims associated with indigenous seeds and traditional farming systems, monitoring progress, identifying emerging "best practices," suggesting solutions to unanticipated problems, etc., can best ensure the sustainability of this newly systematic approach to promoting and incentivizing sustainable seed innovation in India.
I Introduction: Goals, Key Terms, Methodology, and Overview of Key Recommendations

A Goals

This position paper recommends means of incentivizing and promoting research and in situ innovation with agrobiodiversity, in particular, among small farmers in India. The recommendations are made with three primary goals in mind: (i) expanding the role and contribution of small farmers in the Indian economy by helping them become “know-how providers and innovators,” rather than remaining mere “technology/innovation users”, (ii) expanding the choices available to Indian farmers vis-à-vis systems and approaches to agriculture, in order to facilitate a shift towards more sustainable (eco-friendly) agriculture, keeping the interests of all stakeholders, as well as the need to ensure both food and nutritional security, in mind, and (iii) expanding and strengthening India’s organic and circular economy with the help of (i) and (ii) and making it a world leader in the supply of organic seed and food.

The position paper also recommends means of enhancing and expanding research on and with agrobiodiversity and associated Traditional Ecological Knowledge (TEK) based farming systems, by all stakeholders (including farmers, academic researchers and private sector plant breeders). It also recommends means supported by the latest and emerging technologies of generating funds for such research and equitably distributing its benefits. This recommendation is of central relevance to the above-mentioned goals, because research is necessary to better understand and document various unique properties and advantages of indigenous seeds/crops as well as microbial populations and circular (zero waste) traditional farming systems associated therewith. In other words, research is necessary to identify and utilize the full (commercial) value of these diverse crops, microbial populations and farming systems for the benefit of small farmers, the environment, and the Indian economy.

Research and in situ innovation with agrobiodiversity conducted using traditional/eco-friendly farming systems that circulate nutrients from organic waste, support seed and soil health and diversity, while also enhancing small farmers’ incomes and maintaining local socio-cultural diversity, are concisely referred to in this position paper as “sustainable seed innovations”.

B ‘Agrobiodiversity’: Meaning and Scope

The term agrobiodiversity refers to biodiversity that is relevant for agriculture. While it is dominantly thought to comprise primarily of crop/plant genetic diversity, modern scientific research, as well as traditional ecological knowledge systems recognize that in-soil microbial diversity is equally important for sustainable agriculture. While traditional/indigenous/heterogeneous seeds (also called ‘desi beej’)

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are some of the richest storehouses of crop genetic diversity, products, processes and formulations described in traditional ecological knowledge (TEK) systems help support soil and plant health, inter alia, by ensuring optimal beneficial microbial diversity and activity in agricultural soils. In fact, TEK based farming utilizes locally generated farm and animal (organic) waste to create these beneficial products and formulations, thereby helping recycle nutrients from waste, minimizing the need for external inputs and maximizing farm profits. In fact, with growing commercial and research interest in both in-soil (microbial) and on soil (crop) diversity, the relevance of TEK based farming system will also inevitably rise.

C ‘Sustainable Seed Innovations’: Meaning and Scope

‘Sustainability’ is a term that evolved over the last few decades to take on several shades of meaning. The term ‘sustainable development’ that became famous following the Brundtland Report, focused on

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9 Desi beej or indigenous/heterogeneous seeds are seeds that are indigenous to India, locally adapted, and have not been “improved” or made “uniform” (for example, from the perspective of obtaining plant variety protection or for creating F1 hybrids).
development that ensured environmental protection, while also mentioning the social and economic dimensions of sustainable development. Over time, the concept of sustainability has expanded to incorporate, in addition to environmental sustainability, also social and economic sustainability. Although the term ‘sustainable innovations’ is not as commonly used in the literature as ‘sustainable development’ (which is a term that is also widely known and discussed under the United Nation’s Sustainable Development Goals), we borrow from the ‘sustainable development’ concept to define ‘sustainable seed innovations’ as innovations that ensure the following:

1. **Environmental Sustainability**: The innovations must protect, nurture and enrich the environment, inter alia, by enhancing in and on soil biodiversity (a goal pursued by international instruments such as the Convention on Biological Diversity), minimizing waste generation and/or maximizing circulation of nutrients from waste, conserving water, replenishing water tables and maximizing ecosystem services (goals pursued, inter alia, under the UN Sustainable Development Goals);

2. **Socio-Cultural Sustainability**: The innovations must respect, revive and support the continuation of local cultures, traditions and knowledge systems, including festivals, cultures of seed and knowledge saving and sharing etc., while also supporting social development and reducing non-sustainable demographic shifts;

3. **Economic Sustainability**: The innovations and the way they are managed, must support the economic growth and well-being of farmer-innovators as well as the local/rural communities in which these farmer-innovators are working, effectively incentivizing the continuation of the practice of sustainable seed innovations;

4. **Sustainability of the Innovation Process**: The innovations must nurture the spirit of innovation by supporting, through effective frameworks, continuing downstream innovations (both formal and informal) by diverse stakeholders making sure, nonetheless, that transfer of raw materials (seeds, crop genetic resources etc.) necessary for downstream innovations are transparently, and accurately tracked. This tracking is necessary to ensure that economic benefits accruing to downstream innovators are shared with the original innovators/communities of innovators.

**D Methodology Adopted to Compile the Position Paper**

The recommendations emerging from the Sustainable Seed Innovation 1.0 (SSI 1.0) project workshop forms the backbone of this position paper. During the SSI 1.0 workshop (help in September 2017), in order to obtain comprehensive feedback from the 36 experts and small farmers’ representatives present, intensive roundtable discussions were organized and distributed into the following four working groups:

1. Policy, Legal frameworks & Intellectual Property (Moderator: Ms. Sunita Sreedharan)
2. Participatory plant breeding (Moderator: S.C. Thripati)
3. Outreach and awareness of indigenous seeds (Moderator: Shamika Mone)
4. Importance of Research on sustainable seed innovation (Moderator: Mrinalini Kochupillai)

The recommendations received were studied and categorized into the following 10 broad categories by the Research Team:

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10 The report explained the concept of “sustainable development” as requiring several things, such as “meeting the basic needs of all and extending to all the opportunity to satisfy the aspirations of a better life. … "sustainable development must not endanger the natural systems that support life on Earth, the atmosphere, the waters, the soils, and the living beings. … “Environmental protection is thus inherent in the concept of sustainable development, as is a focus on the sources of environmental problems rather than the symptoms.” Brundtland (1987).
11 Purvis, Mao, and Robinson (2019); Brundtland (1987).
14 Advocate, expert in intellectual property law, Indian plant variety protection law and the Biodiversity Act of India.
15 Head of Agriculture Department, Art of Living Foundation.
16 Research Director at the Organic Farming Association of India.
17 (At that time) Senior Research Fellow, Max Planck Institute for Innovation and Competition.
1. Attribution (naming of seeds, inventor-communities and persons)
2. (Economic and other) incentives, including royalty and rewards for farmers, farmer-groups
3. Traceability (of source) of seeds and other information pertaining to best cultivation practices
4. Education (formal and informal channels), and through community engagement
5. Communication channels (e.g. to report problems)
6. Marketing channels for quick sales
7. Quality of seeds, produce etc.
8. Quantity/Availability/Affordability (of seeds)
9. Knowledge creation/verification (including through research) and dissemination
10. Revival/Maintenance of Traditional Ecological Knowledge (TEK) and local cultures

An overview of the SSI 1.0 project research questions and objectives is provided in Annex 1 (Background) of this Position Paper. A summary of the major recommendations emerging from SSI 1.0 is provided in Annex 2 herein below.

Additional research by the research team then resulted in the recommendations compiled in this Position Paper on means through which the group recommendations of SSI 1.0 can be best implemented and accomplished in the short and long run.

Public Consultations & Timeline

In order to obtain feedback and additional suggestions from all the experts present at SSI 1.0 as well as from the general public and a larger audience of interested persons and stakeholders, the research team posted each section of the Position Paper (over the course of several weeks, starting on 28th June 2019) on the Spicy IP India Blog, one of India’s leading blogs, that has an excellent track record in fostering transparency and facilitating public engagement on issues of relevance to society.

Timeline

Comments were welcomed on various blog posts as well as the first draft of the position paper (comprising of the three prongs and the Annexes) till 28th July, 2019. All comments received till 28th July were incorporated in the position paper (based on their relevance to the scope of the position paper).

This final position paper is presented to the Government of India during the Sustainable Seed Innovation 2.0 conference (Traditional Knowledge Meets Modern Science) organized in Bangalore, on 30th July 2019. A copy of this position paper will also be made publicly available on the Spicy IP blog, and will also be submitted for publication in reputed peer reviewed journals and other open public platforms, in an appropriately modified form.

Overview of Key Recommendations

Based on the recommendations received from the multi-stakeholder expert group (including several farmers) during the Sustainable Seed Innovation 1.0 Conference and Project, the research team recommends the implementation of a 3-pronged approach to accomplishing the goal of promoting sustainable seed innovations for the benefit of small farmers, the environment and the Indian economy.

The prongs are:

1. Reviving Traditional Ecological Knowledge Systems of India, that contain rich knowledge on means of protecting and enriching in and on soil biodiversity (including, especially, seed diversity) and ecosystem services;

18 The conference outline is available here: https://idip.leeds.ac.uk/conference/ (last visited: 30 June 2019).
2. Re-designing Curriculums of Agricultural Universities of India and of Rural Agricultural Extension Services to incorporate extensive education and training in farming systems that incorporate this traditional ecological knowledge;

3. Re-leveling the Incentives Landscape, inter alia, by adopting technical solutions such as Digital Ledger Technologies (including blockchain) to overcome hurdles that currently disincentivize research and in situ innovations with agrobiodiversity.

II Accomplishing Sustainable Seed Innovations: The Three-Pronged Approach

With the onset of the ‘Green Revolution’ that brought in high yielding varieties, and modern Mendelian Plant Breeding that brought in F1 hybrids, farmers, including small and marginal farmers the world over, have lost interest and incentive to select, save, resow, improve and share their traditional, indigenous seeds and planting materials. Relying instead on improved seeds that are engineered to perform only on soil treated with chemical fertilizers and pesticides, farmers have also witnessed systematically depleting yields of those (traditional, indigenous) seeds that have not been ‘improved’ or engineered to tolerate such chemical inputs.

It is not surprising, therefore, that more than 75% of the Earth’s crop genetic diversity has been lost. According to some estimates, the loss of indigenous crop diversity and corresponding Native Plant Genetic Resources (NPGRs) has been as high as 97% over the last 100 years. Further, 75% of the world’s food is generated from only 12 plants and 5 animal species, world nutrition is primarily based on a mere 10 crops, of which three, namely, rice, maize and wheat, contribute nearly 60% of the calories and proteins obtained by humans from plants. What is threatened today, therefore, is not ‘food security’, but ‘nutritional security.’

At the same time, according to some studies, non-proprietary germplasm continues to be grown by small farmers worldwide, most of which are located in developing countries, but with a growing number in the developed world also. Globally, an estimated 1.5 to 2.5 billion farmers are small holders, who are most likely cultivate and exchange non-proprietary seeds. In fact, of the estimated 570 million farms worldwide, 500 million can be considered small or family farms, 85% of which are less than 2 hectares in size.

Contrary to what may be popularly believed, small and family farms, produce 80% of the world’s food. It is therefore no wonder that the UN Food and Agriculture Organization (FAO) identifies small and family farms to be the main contributors to global food security. To the extent that these small farmers can be incentivized to engage with non-proprietary germplasm and diversified agriculture, they can also become the key custodians and contributors to nutritional security. Indeed, small and family farmers that have a greater outlook and control over the happenings on their landholdings, are therefore best

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19 The term Green Revolution was coined by the US Agency for International Development (USAID) Administrator William Gaud. See Gullathor (2010), 7. It was meant to make the developing world self-sufficient in food (particularly the staple crops of wheat and rice) by ensuring availability of self-replicating seeds that gave up to 300% higher yields, provided they were cultivated in the presence of chemical fertilizers. However, India (as well as Europe) today, are net importers of chemical fertilizers, spending billions of dollars annually on fertilizer imports. India to foot $8 billion for coal, fertilizers, scrap imports’ Business Standard (India, 21 May 2013); Chanti (2017); Majumdar et al. (2017); Prasad and Shivay (2015); Nanda (2018).
20 Goeschl and Swanson (2003); Kochupillai (2016).
21 It is noteworthy that prior to the development of HYV seeds of Wheat and Rice (funded by the Rockefeller Foundation) under the Green Revolution, traditional wheat and rice seeds were found to not respond favorably to treatment by chemical fertilizers. Athwal (1971).
22 Kochupillai (2016), 67. (See also footnote 39 on page 87).
23 FAO (1999).
24 Ray (2012); Tracy (1903); Seburanga (2013).
26 Bennet (1997); McGuire and Sperling (2016).
27 Montenegro (2015); FAO (1999); McGuire and Sperling (2016).
29 Altieri (2008); Altieri, Funes-Monzote, and Petersen (2012); FAO (2014); Ricciardi et al. (2018).
30 FAO (2014).
suited to conserving, replenishing and improving (agro)biodiversity. It must be borne in mind, however, that adoption of indigenous/heterogeneous seeds is not adequate in itself. Given the fact that such varieties are known to not perform in chemical fertilizer treated soils, a prerequisite to meaningfully ensuring both nutritional and food security, is the revival of soil health via elimination of chemical fertilizer residues.

In fact, reasons supporting incentivization of traditional agriculture, using indigenous, non-uniform, locally suited heterogeneous seeds and planting materials stretch beyond food and nutritional security to the very sustainability of agriculture and food production systems worldwide. Latest scientific research challenges the extent to which Mendelian genetics can and ought to be the sole guiding force of agriculture. The relevance of in-soil (microbial) diversity, the interaction between soil and plant root microbes, and the processes that optimize the microbial populations to enhance nutrient absorption by plants, has now become a major area of scientific research. This microbial diversity, that is key to maintaining soil health (and therefore for ensuring agricultural sustainability) is severely compromised in conventional, high chemical input agriculture. Accordingly, modern scientific research supports a return to TEK-based farming systems that naturally increase soil microbial diversity by efficient use of natural animal and farm waste, thereby preventing soil pollution, supporting nutrient recycling and to enhancing yields of traditional/indigenous and heterogeneous seeds and materials.

Experience shows, however, that when a specific understanding and associated practice has occupied the minds of a people and community for decades, and has also become the most convenient and/or comfortable/practical option (e.g. due to ready and abundant seed availability and the complexity of converting soils from conventional to organic), a shift in approach and attitude does not happen easily or automatically. Systematics efforts are needed to (re)educate and (re)incentivize, not just farmers, but also the entire chain of stakeholders engaged in agriculture, in order to bring about a lasting and sustainable, and peaceful transformation.

Based on the above summary of research findings (SSI 1.0), supported by the findings and recommendations of the expert participants of SSI 1.0, this position paper recommends a three-pronged approach to incentivize and support sustainable seed innovations. The adoption and implementation of these three prongs, supported by continuous research and development efforts are expected to bring socio-economic benefits to small and marginal farmer-innovators engaged in traditional farming using indigenous/heterogeneous seeds, environmental benefits for farms and rural communities, and nutritional security and food diversity to consumers. On the whole, the 3-pronged approach is also expected support the development of India’s bio-economy and make India a global provider of high quality, heterogeneous agricultural seeds and planting materials.

The remainder of this section describes the rationale, justification and means of implementing the three pronged approach, which comprises of:

1. **Prong 1:** Revival of Traditional Ecological Knowledge (TEK) based farming systems
2. **Prong 2:** Re-designing educational and extension service curriculums
3. **Prong 3:** Re-leveling the Incentives Landscape, inter alia, by adopting technical solutions such as Digital Ledger Technologies (including blockchain) to overcome hurdles that currently disincentivize research and in situ innovations leading to sustainable seed innovations.

A **Prong 1: Revival of Traditional Ecological Knowledge Based Farming Systems: Traditional knowledge through the lens of modern scientific research**

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32 Chanti (2017).
33 Chigonda and Rusena (2018); Spiertz and Kropff (2011); Wezel et al. (2018).
34 Lareen, Burton, and Schäfer (2016); Pieterse, de Jonge, and Berendsen (2016); Kumar et al. (2015); Jat et al. (2015); Bender, Wagg, and van der Heijden (2016); Trap et al. (2016).
35 Rusch and Uhl (2016).
Traditional Knowledge: An International Perspective

International conventions, such as the Convention on Biological Diversity (CBD), have long underscored the need to protect biodiversity within the soil (i.e. the beneficial soil microbial diversity) &

Box 1: Seed Storage Story

Laying the Foundation for Innovation

A foundation seed is the ‘pure seed stocks grown for use in the production of registered and certified seed’. When it comes to ‘informal’ farmer-level innovation, foundation seed(s) take on completely different meanings. For instance, one of the many traditional methods of storing seeds includes protecting them within the foundation and walls of homes. Moreover, the ability to store seeds from one year to the next provides the foundation necessary to support future innovations.

In this story, farmers from Andhra Pradesh, Maharashtra and Punjab share their knowledge of traditional techniques for storing seeds. Furthermore, their knowledge of seed-saving exhibits their quest for information, experimentation, and ultimately a journey of learning.

A Variety of Ways to Store Varieties

Seed storage varies according to crop and region. In Punjab, one method involves burning camphor to create an anaerobic environment. The anaerobic conditions within a well-sealed container protect the seeds from any pests. Along with this technique, Ranjit from Punjab adopted a method he learned from south India for storing pulses. The method involves adding approximately one foot of sand on top of the pulses stored in a container or alternating layers of seed and sand. The scientific rational for the sand-mixture method: the sand particles kill insects by acting as an abrasive agent against the insect, and the sand acts as a barrier between seeds and insects. An assessment of traditional methods of pulse storage found them to be inexpensive and eco-friendly, while maintaining high germination, low insect infestation, and low moisture content.

A cucumber certainly contains a lot of moisture, so how does one store the seeds of a cucumber? Sameer in Maharashtra showed us how he stores three varieties of cucumber on the walls of one of his farm’s out-houses. His grandfather built the walls using a special soil that forms under the trampled paths of cattle by compacting and mixing layers of cow dung and soil. To store the cucumber seed, simply cut the cucumber, throw it against the wall and let the soil absorb the moisture. Traditionally, many varieties of seeds were stored in walls and in large holes dug underground.

The method of storing underground, in part, inspired the seed-saving method developed by Ravi in Andhra Pradesh. In Orissa’s tribal areas, he observed seeds stored by digging large holes in front of the houses. The seeds were placed in the holes with paddy grass, then cow dung, and finally mud. Ravi lines bamboo containers with cow dung, on top of the seeds he adds a layer of grass, then a layer of neem leaves and finally seals the container with cow dung. The grass layer absorbs moisture, while the neem leaves act as a natural insecticide. This use of neem is widely known and practiced, while the other aspects of Ravi’s method come from his many visits to tribal areas throughout India.

See the full story: https://idip.leeds.ac.uk/laying-the-foundation-for-innovation/

36 Merriam-Webster.
37 Dhaliwal and Singh (2010).
38 Ahuja, Ahuja, and Thakrar (2011).
39 Prakash et al. (2016).
40 Mannan and Taraman (2011).
41 Boadu et al. (2011).
on the soil (i.e. seed/plant biodiversity). Equally relevant is the recognition and high status given within these conventions to the valuable role played by traditional knowledge & associated systems, practices, & innovations, in maintaining this biodiversity, & using it in a sustainable manner.\textsuperscript{42} The CBD envisages generating social and economic benefits (through “benefit sharing”) for people and communities using, preserving and sharing this traditional knowledge, inter alia, with scientists and others interested in accessing it for legitimate purposes. Ensuring equitable benefit sharing is necessary not only to ensure fair compensation for sharing biodiversity and associated know-how, but also to ensure that communities engaged in protection and in situ conservation of (agro)biodiversity have (monetary) incentives continue their important work. ‘Conservation’ and ‘preservation’, however, are unfortunate terms in the context of (agro)biodiversity\textsuperscript{43}, not least because farmers and farmer communities don’t just conserve this diversity, but constantly improve it and innovate with it (see for example Box 1 and 2). It is therefore not surprising that the CBD encourages international “cooperation for the development & use of technologies, including indigenous and traditional technologies, in pursuance of the objectives of the Convention”.\textsuperscript{44}

In this context, and especially for India, particularly relevant from a business perspective is the exponentially growing popularity of Ayurveda and of products and services derived therefrom, including among European populations.\textsuperscript{45} This growing popularity within Europe (and beyond) of products and services based in Ayurveda, and the expanding consumer trust in this system of knowledge,\textsuperscript{46} makes a strong economic and business case for the adoption of farming methods (and associated business models) rooted in this traditional, time tested knowledge system, and for the re-introduction of farming systems that are based on this knowledge, into the mainstream.

Furthermore, there is growing scientific support and validation of the philosophy and knowledge underlying various TEK based products and processes, as described in the following sub-sections.

(i) The Philosophy of Traditional Ecological Knowledge

Traditional ecological knowledge (TEK) and associated farming systems can be considered a holistic approach to farming that promotes and enhances the health and diversity of agro-ecosystems, and facilitates complex and beneficial interactions between biodiversity, biological cycles and soil biological activities.\textsuperscript{47} TEK based farming systems visualize human beings (and animals, such as cattle) as being a part of nature and consequently aims for co-existence and co-evolution of entities that benefit from each other through ecosystem services (synergies within the ecosystem).\textsuperscript{48} TEK evolves experimentally and has an evolutionary character that verifies the knowledge season after season and is handed down from one generation to the next.\textsuperscript{49} In other words, these systems evolve in harmony with local socio-cultural realities and in accordance with local site conditions. Consequently, they are deeply embedded in local (often unique) cultural, natural, social and economic practices and circumstances.\textsuperscript{50} This essentially means that TEK based farming systems evolve independently in various parts of the world, and while they follow basic principles of nature, they do not follow any uniform ‘recipe’ that is flatly applicable in all regions of the world. Just like personalized medicine, therefore, traditional agricultural practices are highly localized and region specific.

Nonetheless, TEK systems do follow certain basic principles of nature, and work in close collaboration with nature. For example, farmers use the local resources to farm without any external inputs.\textsuperscript{51} The principle of minimized loss of energy, water and nutrients contributes to a more efficient use of available

\textsuperscript{42} CBD (1993a).
\textsuperscript{43} Kochupillai (2019c).
\textsuperscript{44} CBD (1993b).
\textsuperscript{45} Reuters (2017); CBI Ministry for Foreign Affairs (2018).
\textsuperscript{46} CBI Ministry for Foreign Affairs (2018).
\textsuperscript{47} Altieri (2002); Altieri and Nicholls (1999).
\textsuperscript{48} Korn (2015), 201.
\textsuperscript{49} Berkes and Turner (2006).
\textsuperscript{50} Briggs and Moyo (2012), 66; Girard and Frison (2018).
\textsuperscript{51} Chadha, Saini, and Paul (2012).
resources. Principles, such as the carrying capacity of the ecosystem and enhanced biomass recycling promote long-term sustainability. Resources within the ecosystem are used, for example, to build irrigation systems through deep rooting trees or the harvest of rainwater. In other words, in TEK based farming systems, the aim is not to “tame” nature, but to observe and work with natural cycles. Nature is considered as a teacher. Every farmer, therefore, naturally turns into a researcher and innovator because only through careful observation and consideration of the local ecology, such as climate and soil conditions, can the success of planting activities be ensured.

Accordingly, seeds used in TEK based farming systems are also locally selected, multiplied, saved, improved and exchanged. Indeed, seed keeping lies at the heart of traditional agriculture, and has evolved over centuries, with farmers saving seed with desirable traits such as hardiness, yield and adaption to local soils and climates. Seed keeping, when combined with spontaneous natural mutations, results in an astounding diversity of seeds and planting materials which are locally adapted, genetically non-uniform, variable and heterogeneous. The high adaptability and hardiness exhibited by these diverse varieties allows for low cost and low input farming. Further, TEK systems also provide teachings on methods of increasing seed germination rates through various seed preparations (in India called Angara preparation or Beejamrut).

(ii) Traditional Knowledge Meets Modern Science

After decades of focusing on chemical intensive, uniform/standardized farming, the modern understanding of efficient and sustainable farming is presently shifting away from artificial fertilizer and pesticide driven monoculture towards more traditional methods and practices of cultivation. Commonly known among these, are practices of mulching, low tillage, small-scale rainwater harvesting, crop rotation, inter-cropping, multiple cropping and working with the soil microbiome. Many of these practices have been documented in the ancient texts of India, Vedic- (Rigveda, Atharvaveda) and Ayurvedic texts (Charaka Samhita, Sushruta Samhita), dating back to 3000 BC – 1000 BC. More recent studies and developments help to scientifically understand, appreciate and improve upon these ancient practices for modern application. This has led to a growing movement of returning to traditional and natural farming methods in India.

Traditional farming uses several natural bio-stimulants and bio-pest-repellent formulations, which are simple to produce on site (at the farm), using local materials and resources, such as cow dung and urine and diverse local plants. Some preparations that are commonly used in Zero Budget / Natural Farming (one of the most rapidly spreading TEK based farming systems in India), for example, include:

<table>
<thead>
<tr>
<th>Name of agent</th>
<th>Principal contents</th>
<th>Use case</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Beej-amrut</td>
<td>Water, cow dung &amp; cow urine from local breeds</td>
<td>Seed germination enhancer</td>
</tr>
<tr>
<td>2 Jeev-Amrut</td>
<td>Water, cow dung &amp; cow urine, raw sugar, legume flour, soil</td>
<td>Plant Bio-stimulant</td>
</tr>
</tbody>
</table>

52 Bonaudo et al. (2014), 49.
53 Verhoog et al. (2003), 36; Bruins, Evenari, and Nessler (1986); Khadse et al. (2018).
54 Fukuoka in Korn (2015), 159.
55 Mother Earth News Interview with Masanobu Fukuoka (1982).
56 Olsson (2014); Thrall et al. (2011).
57 Cebolla-Cornejo, Soler, and Nuez (2012).
58 Murphy et al. (2007).
60 Srikanth, Tewari, and Mangal (2016).
61 Brown (2013); Münster (2017); Khadse et al. (2018).
62 Khadse Khadse et al. (2018); Brown (2013).
63 Devakumar et al. (2014).
64 Manjunatha et al. (2009); Devakumar et al. (2014).
<table>
<thead>
<tr>
<th>No.</th>
<th>Product Name</th>
<th>Ingredients</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Ghanjeev-Amrut</td>
<td>Water, cow dung &amp; cow urine, raw sugar, legume flour, soil</td>
<td>Plant Bio-stimulant concentrate with longer shelf life</td>
</tr>
<tr>
<td>4</td>
<td>Neem-asta</td>
<td>Water, neem leaves, cow dung, cow urine</td>
<td>Pest repellant / Plant immune-strengthenener</td>
</tr>
<tr>
<td>5</td>
<td>Brahmi-asta</td>
<td>Neem leaves, custard apple leaves, Guava leaves, castor leaves, papaya leaves, pomegranate leaves, cow urine, weeds that are pest resistant</td>
<td>Pest repellant / Plant immune-strengthenener</td>
</tr>
<tr>
<td>6</td>
<td>Agni-asta</td>
<td>Tobacco leaves, green chilli, garlic, neem leaves, cow urine</td>
<td>Pest repellant / Plant immune-strengthenener</td>
</tr>
<tr>
<td>7</td>
<td>Garbage enzyme</td>
<td>Kitchen / yard waste, raw sugar, water</td>
<td>Plant Bio-stimulant / Bio pest repellant</td>
</tr>
</tbody>
</table>

Additional to these products, several processes are used, such as hot composting, mulching, crop rotation, inter-cropping, multiple cropping and low tillage, all of which are already well known and documented. In Europe, for example, these practices are mostly applied in organic farming.65

Any substance or microorganism that is applied to plants to enhance the efficiency of nutrient uptake by plants are called bio-stimulants. Such plant bio-stimulants include preparations composed of organic matter, minerals (such as rock-flour), and microorganisms.66 Biostimulants foster the fertility of the soil-microbiome and consequently, the plant growth and development is improved (facilitated plant metabolism, nutrient assimilation, translocation; water is rendered more efficiently).67 Since biostimulants foster the tolerance against abiotic stress and increase the natural resistance to pests, they contribute to better yields and crop quality.68 Preparations that act like microbial plant bio-stimulants are gaining popularity among Indian farmers (especially among those practicing zero budget or natural farming). These preparations include Beejamrut, Jeev-Amrut and Ghanjeev-Amrut, which are very close to the ancient formulation of Panchagavya (Sanskrit: five products of the cow) which is composed of cow dung, cow urine, milk, curd and clarified butter. Ananda C. (2011) and Chadha et al. (2012) demonstrated the positive effects of these traditional microbial fertilizers.69 Ananda C. (2011) reported similar increase of plant yield when comparing Panchagavya to NPK chemical fertilizer. However, while the chemical NPK fertilizer reduced microbial populations in the soil, Panchagavya increased them, pointing out a possible difference in sustainability for these two approaches.70 Manjunatha et al. (2009) found significant increases in yield of sunflower seeds using the Jeev-Amrut preparation.71 Chadha et al. (2012) also reported significant increase in yields when using these traditional preparations, and also reported their effectiveness in controlling several plant pathogens.72

Chemical analysis of these preparations done by Chadha et al. (2012) also showed presence of bio-available Nitrogen, Phosphorus and Potassium, as well as the presence of several trace elements (S, Ca, Mg, Fe, Mn, Zn, Cu).73 Timmusk et al. (2017) summarizes the effectiveness of employing Plant Growth Promoting Bacteria (PGPB) and Rhizobacteria (PGPR) and concluded that the potential of such formulations can be brought to wider field application by further systematic studies and standardization.74 Mauchline et al. (2017) come to a similar conclusion in their study of the soil microbiome and particularly the interplay of *Pseudomonas* and the wheat rhizosphere, stating that: “a better understanding of the soil microflora, combined with smart manipulation of plant cropping systems may present a reliable future route to sustainable yield improvement and biocontrol.”75

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67 European Biostimulant Industry Council (2019).
69 Ananda (2011); Chadha, Saini, and Paul (2012).
70 Ananda (2011).
71 Manjunatha et al. (2009).
72 Chadha, Saini, and Paul (2012).
73 Chadha, Saini, and Paul (2012).
74 Timmusk et al. (2017).
75 Mauchline and Malone (2017).

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is ample, current research on plant microbe interaction and the soil microbiome regarding agricultural application, all lauding the promise of microbe powered sustainable agriculture.\(^{76}\)

Any natural farming method or agricultural model that aims to be economically profitable, environmentally and socio-culturally sustainable, to preserve and enhance biodiversity and thus increase the resilience of an ecosystem while using minimal or zero external input of nutrients or synthetic pesticides, requires the cultivation of local varieties of (indigenous, heterogeneous) seeds.\(^{77}\) Such varieties are already adapted to their environment over an extended time span and often display high resilience to biotic and abiotic stresses present in that environment.\(^{78}\) To support seed health, TEK farming systems create simple formulations using local biowaste and herbs, that enhance vitality of seeds of local crop varieties. A well-known example of such a formulation is Bheej-Amrut, a seed-stimulant preparation deriving from Indian TEK texts. Bheej-Amrut is typically composed of water, cow dung, cow urine, limestone and local soil and hence easy to produce on site.\(^{79}\) Devakumar (2014) found Bheej-Amrut to contain N-fixing, P-solubilizing bacteria, actinomycetes and fungi. Sreenivas et al. (2009) also reports the presence of indole acetic acid (IAA) and gibberelic acid (GA) producing bacteria in Bheej-Amrut. Furthermore, Bheej-Amrut-treated seeds show an increased germination rate and seedling length.\(^{80}\) These findings suggest the importance of TEK based formulations in promoting sustainable agriculture that also supports the cause of enhanced food and nutritional security. These findings also highlight the need to continue and step up research efforts on and with TEK based farming practices and associated low cost products.

Going beyond India, the know-how for creating another low cost microbial preparation, commonly called “Garbage Enzyme”, has emerged from farming practices of award winning farmers in Thailand.\(^{81}\) Garbage enzymes are produced by fermenting household or industrial fruit and vegetable peels and scraps. Its production is simple and low cost. The Garbage Enzyme preparation is associated with increased solubilization of Phosphorus from solid deposits.\(^{82}\) The efficacy of soluble and mineral Phosphorus enrichment of soils by microbes has been described by Sharma et al. (2013), which points out how Garbage Enzyme could benefit plant vitality and yields in agriculture.\(^{83}\) Other documented uses of Garbage Enzyme includes the treatment of synthetic greywater,\(^{84}\) and waste activated sludge.\(^{85}\) In both use cases, the results point toward increased solubilization of solids from the substrate, which in turn may facilitate bacterial treatment and use of these waste materials as bio-resources.

Other well-documented processes employed in traditional agriculture, and increasingly validated by modern science, include mulching and low tillage, which have been demonstrated to improve several soil properties considered crucial for productive agricultural use.\(^{86}\) Xiao-Yan Li et al. (2001) found increases of corn grain yield of 20 - 95 % by mulching, depending on the availability of water: the drier the year, the greater the improvement of grain yield.\(^{87}\) Low tillage is a practice that is gaining more and more attention in the sustainable farming context and its efficacy has been shown in several studies.\(^{88}\)

Practitioners of TEK based farming, especially when supported by non-governmental organizations that keep track of global developments, remain open to adopting more recently innovated, locally usable, sustainable organic farming methods. An example of this is the embrace of the Berkley Hot composting method by Natural Farming practitioners. This is a simple and low-cost method to fully

\(^{76}\) Finkel et al. (2017); Jansson and Hofmockel (2018); Santoyo et al. (2016).

\(^{77}\) Wezel et al. (2018); Rankoana (2017).

\(^{78}\) Girard and Frison (2018); Turvey, Bryant, and McClune (2018).

\(^{79}\) Devakumar et al. (2014).

\(^{80}\) Nemagoudar et al. (2014); Sornalatha, Tamilarasi, and Esakkiammal (2010).


\(^{82}\) Nazim and Meera (2013); Arun and Sivashanmugam (2015).

\(^{83}\) Sharma et al. (2013).

\(^{84}\) Nazim and Meera (2013).

\(^{85}\) Arun and Sivashanmugam (2015); Arun and Sivashanmugam (2017).


\(^{87}\) Li et al. (2001).

\(^{88}\) Muhumba and Lal (2008); Sharma et al. (2015).
utilize all excess biomass available and rapidly convert it into a versatile bio stimulant for use in agriculture.\textsuperscript{89}

The state of current research as outlined above, strongly underlines the promise of traditional sustainable farming methods, and makes a clear case for the revival of TEK based farming systems, and employing, where relevant both ancient and modern techniques and processes together. It also underscores the need to invest greater funds in researching and reviving these sustainable farming methods, to ensure socio-economic benefits to farmers and to preserve and enhance environmental health and diversity.

The question that arises, of course, is how one can concretely go about reviving and introducing TEK based farming systems into mainstream agriculture. Here, the SSI 1.0 working groups emphasized the relevance of (re)education through diverse channels – both formal and informal. Informal efforts through NGOs and spiritual leaders of India is ongoing. In the following segment, we consider curriculum redesign in agricultural universities and extension services that aim at converting farmers, who have so far been ‘technology takers’, to innovators and technology makers, particularly in the context of seed related innovations and sustainable farming methods (including methods of soil health management, seed preservation etc.).\textsuperscript{90}

\textbf{B Prong 2: Re-designing Education for Agricultural Students and their Teachers}

Recall what was said above about the nature of the seeds that emerge from a traditional culture of seed keeping (and low-input farming). They are well adapted to local conditions, yet without being genetically uniform. That lack of uniformity helps keep the seeds resilient in the face of changing conditions. But farmers also play a key role in maintaining adaptative fit, through continual, "quality control" selection. It is time to consider the farmers, in particular their own, scientifically informed understanding of their choices and the consequences of those choices. What sort of scientific education is best suited to the farmer-as-sustainable-seed-innovator?

At this preliminary stage, raising awareness of the need for a new kind of training should take priority over settling on the exact content of this training. Nevertheless, even now it is possible, in an indicative way, to sketch out reforms in a couple of areas where improvements are not only possible, but thanks to recent research from within the project team, straightforwardly made.

The following section, for the sake of convenience, writes about farmers themselves as the recipients of the envisaged training. Given current structures of delivery of education to farmers in India, where several farmers may have never received a formal education, but receive periodic training from NGOs and Rural Agricultural Extension Officers (RAEOs), it is more realistic, for the foreseeable future, to suppose that the training envisaged below, is not given directly to farmers, but to RAEOs and agricultural university students, who can then go on to disseminate appropriately tailored versions of it to the farmers themselves.

\textbf{(i)} From a “genes for traits” to a “genes, environments and variability” understanding of heredity

After presenting the now-standard way of doing things pedagogically, this section describes a recent alternative, then considers how the values acquired in the introductory genetics classroom might translate into farming practice.

"Genes for traits" genetics teaching: Consider a widely used university-level genetics textbook, \textit{iGenetics: A Mendelian Approach}, by Peter Russell.\textsuperscript{91} Early on, students are introduced to Gregor Mendel, “founder

\textsuperscript{89} Blanc et al. (1997).
\textsuperscript{90} See, for example, Box 1 and Box 2
\textsuperscript{91} Russell (2006).
Box 2 Jitul’s Story

Agrobiodiversity Provides a Golden Opportunity
Jitul Saikia’s story demonstrates a farmer fulfilling the role of scientist, conservationist and entrepreneur. As a sericulturalist, he rears Muga silkworms to produce the rare golden silk.

Golden Silk and Plant Varieties
Included in the riches of India’s agrobiodiversity is the golden silk producing Muga silkworm (Antheraea assamensis) and the host plants on which they depend. Today, air pollution from pesticide drift and the burning of crop residue threaten the health of the silkworm and the continuation of this traditional sericulture. Muga’s specific ecological needs and low adaptability confine the species to the Brahmaputra valley in Assam and a few pockets within other north-eastern states.

Using Host Plant Diversity to Innovate Golden Silk Production
The restricted range of Muga is due in part to a dependency on specific host plants. In 2015, Jitul Saikia received Genome Saviour Farmer recognition for conserving 12 landraces of Muga host plant. Moreover, Jitul uses host plant diversity to innovatively improve silk production by moving the silkworm to different host plants at different stages of the lifecycle. Key to Jitul’s techniques is recognising that host plant varieties differ in chemical composition and morphological structure and these differences matter in sericulture. For example, some host plant varieties improve silk production, others improve egg production (fecundity), some host plants are ideal for high-quality egg production, while the broad leaves of some of the plants provide shelter from the weather particularly during the rainy season.

Jitul insists that host plant diversity must be used in rearing Muga silkworms. Farmers tend to prefer a few varieties of host plant for rearing Muga, but farmers do not match the host plants to the different life-cycle stages of the silk worm. By contrast, Jitul uses host plant diversity to increase production by using different host plants at different stages of the lifecycle. As a result, the size of the larva increases as does silk production. The farmers see that he has improved Muga seed production with 250 eggs or more per lane compared to typical production of 110 to 115 eggs. He also keeps careful records of his experiments hoping to influence the practices of other farmers. However, other farmers have not yet followed him in adopting this innovative technique. Nonetheless, he aims to train other farmers in his techniques to improve their livelihoods.

For video of Jitul’s work and details of his conservation efforts visit: https://idip.leeds.ac.uk/2019/06/11/agrobiodiversity-provides-a-golden-opportunity/

of the science of genetics,” and his famous experiments hybridizing pea varieties. Such a starting point is a global commonplace, at every level where genetics is taught, and has been, to varying degrees, for over a century. Students go on to learn about Mendel’s discoveries of dominance and recessiveness, segregation, etc: discoveries made thanks to his purifying his varietal stocks before crossing them, thus revealing regularities that escaped previous investigators. When, for example, purple-flowering and white-flowering stocks were crossed, all the hybrids had purple flowers, showing purpleness to be dominant over whiteness. And when those hybrids self-fertilized, their offspring showed not just purple

92 University of Leeds (2019).
93 Purkayastha (2016).
94 Goswami, Rabha, and Veer (2016); Kalita and Dutta (2014).
95 Jamieson and Radick, (2013).
but also white flowers, in the ratio 3 to 1. Then the students get to see for themselves how wonderfully well explained this pattern is on Mendel’s simple hypothesis that there are just two kinds of underlying factor, one for purpleness and one for whiteness.\textsuperscript{96}

Russell’s textbook itself comes in two varieties. There is \textit{iGenetics: A Molecular Approach} as well as \textit{iGenetics: A Mendelian Approach}.\textsuperscript{97} But both books have the same chapters, just in a different order. In the Molecular Approach book, as soon as whole organisms come up, we are back with Mendel and his pea hybrids. That is what an intellectual monoculture looks like.

What is the problem? Judged on its own terms, there is no problem at all with this pedagogy. On the contrary, it works amazingly well. If you want to experience how good science teaching can be when it is at its best, take a well-taught introductory genetics course. A century of honing has made this pedagogy exceptionally effective at inducting good students – the ones who want to do well, who really work at the questions at the back of each chapter in order to master the techniques of reasoning – into the science of heredity under Mendelism, and to do it so comprehensively that they lose more or less any appetite or ability they might have had to think critically about what they are being taught.

But there are worries. A recent survey of college and university teachers of introductory genetics across the United States revealed that they were uniformly concerned that, in the actual delivery of their courses, gene-environment interactions come across to students as a low-emphasis, low-priority topic. From the perspective of these teachers, it would not be at all surprising if, despite their good intentions and best efforts, what their students remember after the course is the long-outdated “genes for traits” notion emphasized at the start-with-Mendel beginning.\textsuperscript{98} Part of what makes the standard beginning so permanently attractive is that it is so simple. To understand why a flower has the colour it does, you need to pay attention only to the combination and recombination of flower-colour genes, themselves attractively binary, for-purpleness or for-whiteness. Nothing else matters. Environments, from the genomic to the physiological to the physico-chemical, never get mentioned. Nor is there any interesting variability in the outward characters or “phenotypes.” There is just purpleness and whiteness.

It appears, then, that a misleadingly deterministic picture of how genes work is being instilled through standard genetics pedagogy and its organization around Mendelian hybrids and concepts associated with them. That is problematic in itself, so far as we want students to emerge from teaching with something approximating our own best scientific understanding of how heredity works. It may also be problematic in its implications. We shall refer to implications for agricultural practice below. For now, and more briefly, consider the implications for decisions taken in the context of human health and illness. Increasingly people are acquiring information about their own genetic constitutions.\textsuperscript{99} If teaching conditions them to want to ask only whether or not they have the “genes for” certain diseases, say, and not to want to ask in addition about how differences in genetic background may matter, or differences in wider environments, then that in-curiosity may lead them to make poor choices, leading to worse outcomes. That is one way in which a persistently Mendelian organization for genetic knowledge can hold us back from reaping maximal human benefit from recent advances in what is increasingly known as “post-genomics.”\textsuperscript{100} Another is the potential it creates for strengthening a psychological attitude of essentialism: for thinking that people, like peas, come in genetically defined types, some born with a greater capacity for worldly success than others, with well-known consequences for social inequality.\textsuperscript{101}

\textsuperscript{96} On Mendel’s explanation, all the hybrids are purple because when purple-making factors from the purple-flowering plants meet white-making factors from the white-flowering plants, purpleness is dominant. Only when white-making factors meet a white-making factors – as will happen, by the rules of probability, in a quarter of hybrids’ offspring, given the segregation of white-making and purple-making factors into separate gametes – will the resulting plant produce white flowers.

\textsuperscript{97} Russell (2006).

\textsuperscript{98} We are grateful to Michelle K. Smith for sharing the results of this not-yet-published survey, conducted in connection with ongoing research by her, Brian Donovan and PI Radick.

\textsuperscript{99} Mordor Intelligence (2018).

\textsuperscript{100} Kitcher, (1996), ch. 11; Kronfeldner, (2009).

\textsuperscript{101} Donovan, (2014).
“Genes, environments, and variability” genetics teaching:

There is, fortunately, another way. Recent research re-examines the debate that broke out over Mendel’s experiments after the 1900 rediscovery of his paper on them. The debate was most intense between the Cambridge-based William Bateson, who did more than anyone to promote Mendel’s work as the foundation for a new, experimental, quantitative science of heredity, and the Oxford-based W. F. R. Weldon, who, before his untimely death in 1906, went further than anyone in developing a serious biological critique of early Mendelism. To Weldon, Mendelism represented a backwards step for biology, at a moment when the most impressive work coming out of experimental embryological laboratories in Germany and elsewhere at that moment was reinforcing a lesson that thoughtful biologists already regarded as well established: that, from organs to organisms, the characters that are manifest, expressed, visible depend fundamentally on what is interacting with what. Change the nature of the interaction, and you can change the character. Dominance is not, as with elementary Mendelism, an absolute property of a character, but is relative to conditions, and can be variable as conditions alter. In Weldon’s view, the needed science of heredity was one that gave due prominence to the influence of surrounding conditions on the effect of a bit of chromosome on a body, rather than marginalizing it as a (slightly annoying) complication.

Did this debate matter? Perhaps something like a determinist “genes for traits” notion was inevitable, if not in 1900 in Europe, then sooner or later somewhere or other. But then again, perhaps if Weldon’s interactionist emphasis had been more successful than it was – had he lived long enough to finish his book about it, had he acquired acolytes who sought to extend and defend it (Bateson attracted brilliant ones), and so on – we might now have introductory genetics textbooks that look different from the likes of *iGenetics*, helping to create students with different ideas about how heredity works, who go out into the wide world and think differently, choose differently, act differently.

To test this second possibility in a preliminary way, Radick and colleagues ran a pilot-scale teaching experiment, for which they developed teaching materials designed as if they had come from a “counterfactual” past in which genetics had become Weldonian rather than Mendelian. In this experimental curriculum, students were not launched on the study of genes with a look at what now appear to be wholly unrepresentative systems, e.g. crossings with artificially purified pea varieties. Instead the students were taught from the beginning, and throughout, that genes always have the effects they do against particular genetic backgrounds and within a given range of environments, with “environments” glossed as expansively as possible. For these students, the first, exemplary case for thinking about genes was in relation to the condition of a human heart, where genes, themselves of diverse kinds with diverse interactions, are just one of a large range of heterogeneous elements in the causal mix. And when these students did meet Mendelian patterns, they encountered them not as the Truth around which to hang everything else, but as a special case, interesting precisely because so unusual. Rather than being taken for granted as what heredity looks like when environments do not interfere, Mendelian patterns should excite curiosity about the special circumstances under which they can come about.

Both before and after teaching, students on the Weldonian course were assessed as to their levels of “genetic determinism.” The same was done with students taking a traditional start-with-Mendel introductory course in genetics. What Radick and colleagues found was that, in line with their predictions, students on the Mendelian course were just as deterministic about genes at the end of teaching as at the beginning – there was even some evidence of increased determinism – whereas students on the Weldonian course were less deterministic about genes at the end of teaching.

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102 Radick, (2005); Charnley and Radick (2008).
103 Olby (1987); Bateson and Mendel (2013); Bateson (1928); Darden (1977).
104 Froggatt and Nevin (1971); Farrall (1975).
105 Radick (2016).
106 The Weldonian curriculum can be sampled at [https://arts.leeds.ac.uk/geneticspedagogiesproject/gpp-lectures/](https://arts.leeds.ac.uk/geneticspedagogiesproject/gpp-lectures/).
In sum: a Mendelian curriculum is no longer the only option when it comes to introductory genetics teaching. The Weldonian curriculum shows promise as a curriculum that, in better alignment with 21st-century understandings, helps students grasp gene action as always taking place in a context, with results that in consequence can be hugely variable.

(ii) How values acquired in the genetics classroom might translate to farming practice

With the two genetics pedagogies in view, we can now pursue a further question: What, exactly, might the affinities be between a start-with-Mendelism, “genes for traits” training in genetics and “farming-as-spraying” industrial agriculture? Or, to put the same question from the opposite direction, what, exactly, might the affinities be between a more Weldonian, interactionist, “genes, environments and variability” training in genetics and the more sustainable style of agriculture envisaged in Prong 1 this position paper, where a revival of TEK based farming is recommended?

It appears that a farmer taught well within a Weldonian curriculum has a better shot than a Mendelism-trained farmer at acquiring the following three, sustainability-promoting cognitive attitudes:

- No indifference to the role of the environment in bringing about phenotypic effects
- No presumption in favour of hybrid seeds
- No presumption against a variety whose attractive character is region-specific

Let us consider each in turn:

- No indifference to the role of the environment in bringing about phenotypic effects. Imagine our farmer in an Agricultural Extension classroom where, from the start and throughout, it is hammered home that a bit of chromosome has its effect on a body in a context, under conditions – and that is always the case – it is never not the case – and if it seems that you can forget about the conditions, that is because environments have become standardized. Indeed, one perspective on post-Green-Revolution agriculture sees it as an agriculture which seeks to adapt local environment to globally distributed seeds, with the adaptation taking place thought the use of machinery, pesticides, herbicides, fungicides, intensive irrigation, etc. Farmers are never invited to see what they are doing in that way; rather, they are invited to see the seeds they buy as genetically superior, full stop, and to see all the accessories that are needed to bring out that superiority as merely damping down whatever might inhibit the full realization of that superiority. By contrast, a Weldonian farmer would be alert to how profoundly dependent the marketed seeds are on re-engineered surroundings, and so be better positioned to compare and contrast the environmental toll of using those seeds as against that of using local seeds already adapted to local conditions.

- No presumption in favour of the superiority of hybrid seeds. The vocabulary of “F1 hybrids” was introduced by Bateson, as a way of labelling the offspring of an initial cross: the first “filial” generation. When two lineages are crossed, sometimes the character of the hybrid will resemble one parent or the other, as with Mendel’s peas. But as Mendel knew, there are also crossings where the hybrid character is unlike either parent but is instead distinctive, sometimes even attractively so. It had been a perennial frustration for farmers and breeders and horticulturalists that such hybrids tended not to “breed true” but instead to have offspring with a mix of the characters. As Bateson was the first to point out, Mendelian principles explained that “breaking-up” of the hybrid character, and even, via segregation, explained why the resulting characters included the parental characters and came in the proportions they did.
Hybrids, and above all hybrid corn, went on to become the great emblem of the power of Mendelian genetics to deliver impressive results agriculturally.113

The notion that hybrid vigour (heterosis) and high yields go hand in hand persisted through the Green Revolution, though its emblematic innovations were non-hybrid wheat and rice plants.114,115 Yet for decades, the geneticist Richard Lewontin has been arguing – another instance of counterfactual history of genetics – that there was no inevitability here. We might well have had corn as high-yielding as the hybrid corn that Nikita Kruschev famously came to admire, yet produced through open pollination and selection. But it was not in the financial interests of anyone selling the corn to produce the seeds by those means. The early promoters of hybridization were entirely plain-speaking about the fact that, from the breeder’s point of view, the great advantage of using hybridization is that farmers need to come back to the market – and so to the breeder – year on year if they want to plant those seeds. With non-hybrid seeds, the breeder loses all control after that first sale. With hybrid seeds, control is maintained.116

• No presumption against a variety whose attractive character is region-specific. Recall the story of the farmer Jitul from Assam, who matches different plants with different parts of the life cycles of silk worms. By conserving geographically highly-delimited varieties of the plants on which his silk worms grow, he has been able to optimize the production process. He is, in the old expression, doing well by doing good: creating a market niche for a unique product in a way which maintains otherwise threatened biodiversity. And the fact that the plants mainly thrive in just a few valleys in Assam does not count against those plants, reducing their value. On the contrary, here is a marvellous example of someone working with gene-environment interactions rather than fighting them.

Of course, training in genetics is just once facet of farmer education, and training for a more sustainable future will require coordinated changes across the curriculum.117 As a second, shorter example – but one that will lead us towards Prong 3 of this position paper – considers how farmers might usefully be taught to think in fresh ways about their seed related innovations as their own or their community’s innovations, and therefore, rightfully claim adequate monetary compensation for sharing their innovations, not least with the aim of supporting rural economic growth and development in India.

(iii) From an “IP-narrow” to an “IP-broad” understanding of the ownership of innovations

Until recently, for farmer education, there would have seemed no point devoting any classroom time to intellectual property – “IP” for short. IP meant patents, plant variety protection certificates, and other legal instruments by which innovators acquire the state-sanctioned right to prevent other people from unfairly profiting from their innovations. In the world of seeds, such instruments were the province of the so-called “formal sector”: the firms and associated laboratories that were in the business of bringing new seeds to market. So, for those concerned to incentivize innovation with seeds, a choice seemed to be faced. Either one could pay attention to the incentivizing role of IP, in which case, automatically, one was excluding farmer-level innovation in favour of the formal-sector firms. Or one could concentrate on farmer-level innovation in the informal sector, where the seed savers and sharers, individual and collective, operated independently (but not in isolation) from the formal sector, and independently (as well as in isolation) from the legal world of IP. After all, the kinds of “open-source”, genetically and phenotypically non-uniform seeds in which the seed savers and sharers dealt simply were not the sort of seeds that could satisfy the criteria for even the lowest levels of legal protection.118 Any

113 Ho, McCouch, and Smith (2002).
114 Wilkes and Wilkes (1972); Feder and O’Mara (1981).
115 Scobby (2010); Pingali (2012).
116 Lewontin (1991), ch. 3.
117 On room for improvement in the way genetics is taught in India generally, see Gupta, (2019).
118 The section of this position paper on “Legal and Ethical Issues in the Current System,” discusses an attempt within Indian law to recognize the work done by farmers in developing new varieties. The section highlights how the retention of the DUS criteria (Distinctness, Uniformity and Stability) means that it is often difficult for farmers’ indigenous seed innovations to get the offered protection, and even if the protection certificate is granted, downstream uses are not compensated unless the farmers’ variety is used in a breeding program. Even more problematically, the criteria are contrary to the embracing of genetic variability as a major asset for sustainable agriculture.
concern with innovation in this sector would have to concentrate on other kinds of incentive, most obviously those to do with the enhanced status that comes with being known as an innovator.

But there is another and potentially more fruitful way to look at the situation. Patents, plant variety certificates and so on are one form of IP. Let us call that form “IP in a narrow sense,” or “IP-narrow.” But the ownership of knowledge can take other forms: “IP in a broad sense,” or “IP-broad.” And in the sciences, as long ago recognized by the sociologist Robert Merton, public crediting as an innovator, and the status flowing from it, is the major incentivizing form of IP. To be hailed by the community as the discoverer of a new species or law of nature, with one’s name appended to it forever more, is the goal for the ambitious, who, in exchange for the promise of a fair deal, willingly share their discoveries with the community as soon as possible. In Merton’s view, this credit-distribution mechanism was absolutely crucial to the ceaseless innovation that has been Western science’s trademark since the seventeenth century. In the Indian context, research has shown that farmers, when given the (hypothetical) choice of retaining exclusive rights over any new seeds that they might (hypothetically) develop, preferred that their seed spread far and wide to other farmers and villages, not only to bring a good name to themselves, but also a good name to their community and country (from where the new seed emerged). In this context, a second form of broad IP, called “productivity claims,” asserted on behalf of a body of knowledge, is very relevant: Productivity claims, to explain in simple terms, are claims from any person (or community) that a body of knowledge (or, in the context of this position paper, a sustainable seed related innovation) provided the foundation for follow on knowledge (and innovation) creation. From early days, Mendelian genetics was promoted as the intellectual key to future success in plant and animal breeding. So successful were Mendelism’s partisans that it was and remains difficult to tease apart the reality from the PR when it comes to what breeders, and the rest of us, actually owe to Mendelism. As we have seen, in the case of twentieth-century American seed firms, and the scientists who served them, seeds created through hybridization were attractive in the first instance because, in the absence of patent protection for novel varieties, hybrid seeds ensured future profits for the breeders. And once breeders began concentrating on hybrid varieties, innovative activity in the sector increasingly clustered around hybrid seeds, which duly improved. In due course, unprecedentedly high-yielding varieties were developed. But the notion that they could only have been developed that way is groundless.

Returning now to farmer education for a more sustainable future: we ask, “How, if at all, can IP arrangements be used to incentivize farmer-level sustainable seed innovations in India, in a way that not only strengthens the traditional culture of seed sharing and exchange but promotes the wider goals of sustainable agriculture?” The answer lies in adopting means that recognize and reward legitimate “productivity claims.” This requires systems to be put into place that maintain clear records of where a specific sustainable seed innovation emerged, where the innovation was transferred (i.e., tracing the chain of transfer) and for what purposes it was used. The system must also facilitate payments, not only of bulk one time payments, but also time limited “royalties” for various categories of use. How such a system can be arranged using the latest technologies is discussed in the next prong. However, it is necessary to clarify at this juncture that while a system based on free sharing is laudable (not least because of its selflessness and moral basis), it is neither sustainable from an environmental nor from a socio-economic perspective because, as discussed below, it results in ever diminishing incentives to engage in sustainable agriculture using indigenous seeds and eco-friendly farming practices. For farmers and their communities to understand that the systematic crediting of their (often collective) innovative activity with indigenous seeds is an essential part of putting Indian agriculture on a more sustainable (economic and environmental) basis, is of paramount importance. It will boost the rural economy and make small farmers economically better off. It will also be empowering for small farmers and farmer communities, giving them a greater stake in the system, and therefore greater incentives for its good

119 Charnley and Radick (2013).
120 MacLeod and Radick, (2013).
121 Kochupillai (2016), 213.
122 Charnley and Radick (2013).
management, not just individually, but also collectively. Likewise, it can only empower farmers to know something of the history of how hybrid seeds came to seem so irresistible, and to see it as a history in which different forms of IP were interacting. It will help them resist talk of how, by failing to embrace hybrid seeds, they are dropouts from scientific and technical modernity. At the same time, it will embolden them to see the value in developing their own productivity claims, in support of the particular seeds they work with, and more generally in support of reviving Traditional Ecological Knowledge (TEK) based sustainable farming systems.

(iv) Other educational efforts that will be necessary

In addition to the above educational efforts, it will also be necessary to educate farmers on how and why to use the blockchain/DLT facilitated system that is envisaged in Prong 3. While dapps for farmers’ use are easy to run on smart phones, initial grants (similar to subsidies) might be needed to ensure that farmers are able to acquire the necessary smart phones. Once these phones are acquired, RAEOs and NGOs would also need to step in to educate farmers on how to use these smart phones and the dapps therein. Education on how to access and use the nodes and the associated infrastructure for safely depositing seeds for sale on the blockchain marketplace, will also need to be given to farmers.

C. Prong 3: Re-leveling the Incentives Landscape: Blockchain/DLT supported incentives for sustainable seed innovations

Research has shown that while a large number of incentives exist that promote and support formal (private sector) innovations in plant varieties and plant breeding efforts, very few incentives exist for informal (farmer level) in situ innovations with agrobiodiversity. This imbalanced landscape of incentives is largely responsible for sub-optimal sustainable seed innovations, not least because several existing policies and laws act like ‘ perverse incentives’, i.e. incentives that in pursuit of other goals, end up disincentivizing agrobiodiversity conservation and improvement. Yet, as stated above (Prong 1), ‘conservation’ is an unfortunate term in the context of the work done by farmers on and with agrobiodiversity and associated TEK. Indeed, farmers are not just ‘conserving’, but are actively innovating in situ, with various aspects of agrobiodiversity and TEK based farming systems. Accordingly, as discussed above, from IP-Narrow, which focuses only on pigeon holes of existing intellectual property rights, it is necessary to make a shift towards IP-Broad systems that respect ‘productivity claims.’ This shift would support the re-leveling or re-balancing of the incentives landscape, giving farmers, scientists and industrial players, a fair choice between sustainable ‘high value’ systems of agriculture and conventional ‘high-yielding’ ones.

In a broad sense, productivity claims are a kind of ‘right to attribution.’ Within existing intellectual property rights regimes, however, only copyright law (within its ‘moral rights’ framework) recognizes and protects the right to attribution. Within patents and plant breeders’ rights regimes, such a system does not exist – these regimes operate on a ‘first come’ basis. Other legislations, notably the CBD, the Nagoya Protocol and the Seed Treaty, have attempted to establish systems that recognize and reward a type of “productivity claim”, particularly of communities that have contributed their PGRs for further downstream research and development. However, as is seen in the context of global attempts to mandate access and benefit sharing regimes vis-à-vis access and use of Plant Genetic Resources (PGRs) under these regulations, protecting the right to attribution, and thereby recognizing and rewarding productivity claims, has not been easy in practice. In fact, the system has met with little, if any, success. In this section, we look at the key features of an emerging technological solution, namely Digital Ledger Technologies (DLT), and a more recently evolved version of DLTs, namely, blockchain, to see if technology can assist in implementing the letter and spirit of well-meaning international treaties such as the CBD and the Seed Treaty. Section III then looks at what changes are needed in existing legal regimes to further re-balance the landscape of incentives and ensure smooth roll out of the three prongs.

125 Kochupillai, (2016), 144-147.
126 For a distinction between ‘high value’ and ‘high yield’ agriculture, see Kochupillai and Radick (2019).
Box 3: Sona Moti - Starting with a Handful of Gold

We begin this story with the Pingalwara ashram providing a handful of seeds with the instructions to grow it for the benefit of humanity to Nagpal, a farmer with the Art of Living. From there tests conducted by the Art of Living revealed the grain to have superior nutritional qualities. The photo on the right shows the ceremony where Sri Sri Ravi Shankar gave this relatively unknown variety well-deserved publicity. The name Sona Moti translates to golden pearl to describe the unique round shape and golden colour of the emmer wheat variety. In naming this variety, Sona Moti, Sri Sri Ravi Shankar has differentiated the ancient grain from others available on the market (an example of intellectual property broad). Moreover, the story of Sona Moti is part of a wider comeback of ancient grains, particularly a growing recognition of the importance of emmer wheat varieties.

Emmer Wheat: An Ancient Grain Coming to a Plate Near You

Ten thousand years ago emmer wheat was amongst the first cereals domesticated. Emmer is a hulled wheat distinguished from the free-threshing wheats by the persistent encasement. The extra protection allows it to grow in mountainous areas with poor soil conditions. Customer recognition of healthy properties has created a comeback for emmer wheat. For instance, in Italy, the market for hulled wheats increased by about 15% per year and farmgate prices increased some 30% per year from 1998 to 2000. Moreover, emmer varieties provide a supply of useful genes in wheat breeding due to inherent resistance to rusts, powdery mildew, tolerance to heat and drought, and suitability to marginal lands. Indeed, productivity gains in wheat production in India during the Green Revolution might not have happened if it were not for the Sr2 (stem rust resistance) gene from emmer wheat.

Punjab: Paying a High Price to be India’s Granary

The Green Revolution first came to India through Punjab. Initially seeming to heap the greatest benefit from improvements in yields, Punjab has now plateaued in terms of productivity. Moreover, productivity increases happened because of the increasing use of costly inputs. Economic studies conducted throughout Punjab provide clear evidence of considerable economic hardship in many farming communities. From economic strife, social issues inevitably follow, the most notable being farmer suicides. To address these issues, many have argued for a transformative shift in agricultural practices in the region. Clearly the work of the Art of Living in securing markets for Sona Moti is paramount.

For continued success, the integrity of the product must be maintained. Pingalwara Ashram chose a most suitable farmer to entrust with the seed. Not all farmers take the care necessary, and have the knowledge for seed conservation. Nagpal has been training farmers in techniques to avoid cross-pollination and seed contamination to ensure the purity of the seed and product integrity. Indeed, Nagpal felt reluctant to share the seed with farmers who did not have the knowledge to maintain seed purity.

129 Zaharieva et al. (2010).
130 Zaharieva et al. (2010).
131 Sidhu and Singh (2018).
133 Brown (2013).
**Ancient Pearls of Wisdom**

The price for Sona Moti cultivated with natural farming practices catches 75-80 rupees per kilogram by comparison the price for other organic wheats fetch 30 rupees per kilogram. Sona Moti attracts a higher price due to specific nutritional qualities. The low sugar content of Sona Moti makes it ideal for diabetic patients. Moreover, Sona Moti has three times the folic acid compared to any other grain, and an exceptionally high mineral and protein content. These qualities would not be known and would not be conveyed to customers if it were not for the work of the Art of Living. The story of Sona Moti demonstrates the important connections between intellectual property in a broad sense and generating financial capital/economic sustainability. Intellectual property broad, in the form of the name Sona Moti, distinguishes the variety from other available products enabling consumers to make informed decisions. Read more about this story: [https://idip.leeds.ac.uk/2019/07/01/ancient-pearls-of-wisdom/](https://idip.leeds.ac.uk/2019/07/01/ancient-pearls-of-wisdom/)

The role of small farmers is central to accomplishing the goal of sustainable seed innovations, which, in turn, contributes significantly to securing global food and nutritional security, ensuring sustainable agriculture, and promoting sustainable innovations in seeds and plant varieties. In fact, (small) farmer-custodians of agrobiodiversity are often engaged, knowingly or unknowingly, in farmer level (informal) seed improvements, leading to the creation of new seeds and planting materials that retain desirable characteristics of locally adapted landraces (such as natural pest resistance and better taste), while also delivering greater yields in marginal environments where formally improved seeds fail. Such *in situ*, informal seed improvements by farmers are, in fact, more widespread than one might imagine, and have been identified using terms such as “informal innovations” and “sustainable innovations.”

However, research has shown that farmer-custodians of agrobiodiversity have little incentive to continue using, cultivating and improving landraces, locally suited indigenous/traditional seeds or planting materials and farmers’ varieties (and thereby conserving the PGRs therein), especially when faced with the option of cultivating formally improved, high yielding varieties. This situation is exacerbated as farmers are unable to secure a regular market and good price for their varieties, in part, because farmers’ varieties are inappropriate candidates for protection under existing intellectual property protection regimes, especially in their current narrow/formal construction (as discussed in Prong 2 above).

The culture of sharing prevalent among farmers, coupled with their inability to monitor the chain of transfer of ownership as well as the specific end use(s) to which their varieties are put (e.g. simple consumption or downstream research), also currently act as barriers preventing the emergence of robust and profitable marketplaces that support sustainable use and monetization of PGRs, especially for the benefit of small and marginal farmers, that are by far, especially, but not exclusively in countries like India, the sole or primary custodians and *in situ* improvers of PGRs.

While several regulations in India (and globally), notably the Biodiversity Act, 2000 as well as the Protection of Plant Varieties and Farmers Rights Act, 2001 seek to secure benefits for farmers via ‘benefit sharing’ mechanisms, according to research, the number of cases of benefit sharing have been low to non-existent. These regulations, have, in short, been unable to facilitate the tracing and/or honest and comprehensive documentation of uses to which farmers’ PGRs have been put. It has been

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134 Kochupillai (2016); Hasan and Abdullah (2015); De Schutter (2009); Lehmann (1981); Smith, Elliott, and Bragdon (2015).
135 Nagarajan, Smale, and Glewwe (2007); Ajani, Mgbenka, and Okeke (2013); Nyong, Adesina, and Elasha (2007); Nazarea, Rhoades, and Andrews-Swann (2013).
137 Kochupillai (2016). See also, Boxes 1, 2 and 3 in this Position Paper, as well as additional farmer stories on the SSI Project website, here: [https://idip.leeds.ac.uk/](https://idip.leeds.ac.uk/)
139 Kochupillai (2016); Salazar, Louwaars, and Visser (2007); Correa (2000); MacLeod and Radick (2013).
140 McGuire and Sperling (2016).
141 Kochupillai (2019a).
142 Ruiz and Vernooy (2012); De Boef et al. (2013); Bisht, Mehta, and Bhandari (2007).
143 Tsioumani (2018).
challenging, to say the least, to implement access and benefit sharing (ABS) systems, including those established under the CBD, the Seed Treaty, as well as under various national laws that implement its letter and spirit.\textsuperscript{144}

Accordingly, in addition to recommending large scale (re)education, the SSI 1.0 expert working groups made several observations and recommendations highlighting the relevance of the traceability of any and all indigenous seeds to source. It is relevant to note here that unlike proprietary seeds that can be recognized by unique, uniform features that are registered in the Plant Variety Register, the inherent variability of traditional/indigenous seeds, which is also their greatest asset, lead them to display varying phenotypic characteristics in each growing season,\textsuperscript{145} and in every different location they are cultivated in,\textsuperscript{146} making it difficult to recognize their true origin. While these seeds may be, broadly speaking, more easily identifiable by their unique nutritional or other features when grown in specific regions and soils, they will inevitably change their appearance, which is the currently the most important (and the quickest) means through which infringements of plant breeders rights are recognized.\textsuperscript{147} Absence of any means of tracking/tracing farmers' indigenous seeds to source, leads, again, to lack of any means of ensuring monetary benefits for those who are originators and preservers/improvers of indigenous seeds in various/diverse locations. This, again, systematically removes all monetary incentives for (small) farmers to engage with \textit{in situ} agrobiodiversity conservation, improvement and dissemination.

Further, it is seen in several farming communities that while the entire community may be engaged in the cultivation of specific (traditional) crops, there are a few farmers that are particularly good at selecting the best seed and saving it for the next harvest. These farmers then become the farmers that all other farmers go to if they fall short of good seed for any growing season (see for example, the role that the farmer Nagpal seeks to play in the Sona Moti Story, Box 3). However, once the seed goes out of the hands of a farmer, there is neither any quality control possible, nor any traceability as to downstream uses.

Also, the role played by the entire farming community in collectively conserving and improving any indigenous/heterogeneous seed in various locations (and under diverse biotic and abiotic conditions/stresses) is not acknowledged or rewarded - indeed, the lack of uniform denominations makes this acknowledgement and reward rather difficult, if not impossible. In the Sona Moti story, for example, we notice that similar grains are being cultivated in various regions of India but were not identified (or identifiable) under a common name. Now, with the christening of the grain, this identifiability is made possible, but is still difficult because there is no easily accessible database that farmers can consult to check if their grain is (similar to) an existing grain with specific desirable properties (e.g. in the case of Sona Moti, high folic acid content).

Blockchain/DLT systems, together with AI/Machine Learning systems, can help in each of these instances by supporting decentralized quality control (Blockchain), enhancing traceability of a seed to its origin/source (blockchain), ensuring monetary reward (e.g. in the form of micro-royalties) for all who participate in the conservation and improvement of any indigenous/heterogeneous seed in any location (Blockchain + AI), while also helping 'recognize' seeds from various locations as the same or closely similar variety (AI/Machine learning systems). To begin with, therefore, an attempt is made to explain Blockchain/DLTs with the help of their key features/attributes. It is noteworthy that these key attributes can and are being used in multiple use cases and business models. However, for each specific use case, various questions and issues need to be resolved in order to ensure that a sustainable and ethical solution is designed, taking all stakeholders’ interests and multi-disciplinary concerns into account (see Section III and Annex 3 herein below for details)

\begin{itemize}
  \item \textbf{Digital Ledger Technologies/Blockchain: A Brief Introduction}
\end{itemize}

\textsuperscript{144} Welch, Shin, and Long (2013); Aravanopoulos (2011); Kamau, Fedder, and Winter (2010).

\textsuperscript{145} Girard and Frison (2018); Berg and Raaijmakers (2018).

\textsuperscript{146} Girard and Frison (2018); Berg and Raaijmakers (2018).

\textsuperscript{147} Jondle, Hill, and Sanny (2015).
Blockchain technology, a special version of the more generic ‘digital ledger technologies’ (DLTs), came into being around 10 years ago with Satoshi Nakomoto’s white paper on Bitcoin. More recently, these technologies have been in the media, not only because of ongoing efforts of the Indian government to ban cryptocurrencies, but also because several supporters of these technologies claimed early on that they hold at least the potential of resolving “virtually every human problem in existence,” notably problems associated with trust (or the lack of it). While a lot of what is associated with blockchain is labelled as ‘hype’, blockchain based applications and platforms have emerged and are continuing to emerge rapidly, and are being embraced, not only by companies, but are also increasingly gaining acceptance by national governments who are choosing to permit blockchain based businesses, while covering them under existing or new regulations. Various corporations and governments worldwide have also embraced several blockchain based business models and use cases ranging from supply chain management, land registry management to voting systems and e-governance.

While its use cases in agriculture mostly revolve around supply chain management (“from farm to fork”), recent research, discusses a new conceptual understanding of these technologies, under which they can be used as a means of promoting and incentivizing research and in situ innovation with agrobiodiversity. As discussed elsewhere, in situ conservation is a pre-requisite to in situ sustainable seed innovations (especially by farmers/informal sector). This technology, especially when combined with Artificial Intelligence (AI) applications, can also help small farmers (including farmers whose stories have been described in Boxes 1, 2 and 3 above) digitally trade and monetize their know-how and innovations. When traded with the assistance of these technologies, small farmers can sell or share (individually or collectively) their indigenous/traditional seeds in “digital marketplaces”, better assured of traceability and ‘benefit sharing’. These technologies can also help monetize the sharing of know-how associated with the cultivation of these seeds in unique local conditions.

These technologies hold significant promise although they are, relatively speaking, in a nascent stage of development. The following sub-sections attempt to describe, in the simplest terms possible, the features of these technical solutions, particularly of Blockchain/DLTs that make them promising for the purpose of promoting and incentivizing Sustainable Seed Innovations, especially by farmers. It also discusses how these technologies can also be used to incentivize and raise funds for research on and with agrobiodiversity in a way that enhances farmers’ incomes. Section III then highlights the legal and ethical issues that need to be addressed in order to ensure that the technology leads to equitable and desirable outcomes, rather than inequitable, and illegal ones.

(iii) Digital Ledger Technologies/Blockchain: Overview of Key Features Relevant for incentivizing Sustainable Seed Innovations

Blockchain technology or DLTs are technologies that can be understood and explained in many ways, at various levels of abstraction. For our current purposes, it is useful to think of blockchain/DLT as a technology that permits secure data collection, arrangement, storage and transfer in an immutable or change sensitive manner (so called ‘immutable record keeping’). The data typically entered into a blockchain is often data about transactions – i.e., who gave what to who, when, where, in what quantity etc. This feature, namely, immutable record keeping, is one of the central and most important features

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148 Nakamoto (2008);
149 Walch (2019);
150 Allen (2018); Partz (2019);
151 Zmudzinski (2019); vom Brocke et al. (2018);
152 Agrawal, Sharma, and Kumar (2018); Casado-Vara (2018); Perboli, Musso, and Rosano (2018); Queiroza (2019);
153 Ayed (2017); Hanafatunnisa and Rahardjo; Noizat (2015); Aste, Tasca, and Di Matteo (2017);
154 Zago (2018); Partz (2019); Zuckerman (2018);
155 Lin et al. (2018); Ge 2017; Leng et al. (2018); Tian 2016; Lin et al. (2018);
156 Kochupillai (2019a);
157 Kochupillai Kochupillai (2016);
158 Kochupillai (2019b);
159 Drescher (2017).
of the technology for our purposes, namely, the purpose of promoting sustainable seed innovation. The technology permits the traceability of the source of any transacted good (e.g. seeds), to its origin.\textsuperscript{160} It can perhaps already be stated, however, that because, originally, blockchain was a technology designed primarily for digital (transactional) data, its use for tracing physical transfer of goods has to be accompanied with a plethora of other technologies and safeguarding measures, including, for example, tamper proof packaging, IoT devices, and in case of seeds, technologies such as biomarker technologies.

Beyond the ‘immutable’ record keeping feature, a second valuable feature of DLT or Blockchain, is its ‘distributed’ (as opposed to ‘centralized’) structure.\textsuperscript{161} This means that because data stored on a blockchain is in digital (and not physical) form, blockchain creates a systems where multiple copies of the data can be simultaneously stored (and the transaction history automatically updated, albeit, currently with some time lag) on various computers in different parts of the globe (each computer that has a copy of the full transaction history, is called a ‘node’).\textsuperscript{162} This distributed structure ensures that no one ‘node’ can tamper with the data or transaction history without changing the record in all other nodes. The larger the number of nodes in a blockchain ecosystem, therefore, the more difficult it is to tamper with (change) transaction history. This feature makes the network much more trustworthy than any current ‘centralized’ third party intermediary. For this reason, blockchain technology is said to eliminate the problem of [lack of] trust that disincetivizes certain types of transactions.

In addition to the above two features (i.e. immutable record keeping and distributed/multiple digital ledger copies), an additional feature that can optionally be added to any blockchain system, is the feature of so called “smart contracts”. It is noteworthy here that ‘smart contracts’ are neither ‘smart’ nor truly ‘contracts.’ They are, essentially, self-executing software, i.e., software that automatically triggers a series of digital occurrences/happenings as soon as a pre-determined set of conditions is fulfilled.\textsuperscript{163} Thus, for example, a blockchain software could (soon) be so coded as to make sure that as soon as a bar or QR code on a package of seeds is scanned by a specific system at a specific location (e.g. the buyer’s premises), a transfer of payment is automatically made from account A to account B. Although this system is extremely complicated, it has been successfully deployed to ensure payments to specific parties as soon as certain conditions are fulfilled, without the need for a third-party intermediary (such as a bank).\textsuperscript{164} The system, or the code underlying the system, then replaces the “trusted third party intermediary”, reduces transaction costs, delays, and a host of other problems, including problems that may be result of corruption or breakdown of one of the nodes/computers in the system.

(iv) Blockchain/DLT and In Situ Innovations with Agrobiodiversity

As discussed above, three major hurdles that need to be overcome in order to facilitate sustainable seed innovations (especially by small farmers) as well as monetization of sustainable seed innovations for the benefit of small farmers and their rural communities are: (a) the issue of traceability: the origin of indigenous seeds is rather difficult to trace to source, in part because such seeds often don’t have one common or popular name with which they are known across a nation or region, and in part because the phenotypic characteristics of such seeds are very likely to change with every new season or every new region or condition (climate, soil) in which they are cultivated; (b) the issue of trust: lack of trust among farmers as well as national governments, that persons or institutions that take ‘samples’ of the seeds/agrobiodiversity or traditional knowledge associated therewith, will indeed share benefits with farmers. This results in, on the one hand, farmers’ unwillingness to share seeds/agrobiodiversity (or know-how associated with their cultivation) with scientists, and, on the other, national governments’ imposition of incredibly strict bureaucratic hurdles on any party that seeks to access (agro) biodiversity from within their territories; and (c) the general lack of monetary incentives to cultivate using indigenous seeds (as discussed above).\textsuperscript{165} Adding to this lack of monetary incentives, is the lack of

\begin{itemize}
  \item Kim, (2018); Tian (2016); Queiroza, (2019).
  \item Dorri et al., (2017); Ohnes, Ubacht, and Janssen, (2017).
  \item Zyskind and Nathan (2015); Puthal et al., (2018).
  \item Iansiti and Lakhani, (2017); Law, (2017); Kim, (2018).
  \item Nofer et al., (2017).
  \item See Section II of the Position Paper above. Also see Kochupillai (2016); Kochupillai, (2019c).
\end{itemize}
adequate education/know how among several farmers on how cultivating indigenous seeds using TEK based farming systems can help maximize environmental and economic gains of farmers (see Prongs 1 and 2). Currently, because of the systematic ‘education’ of farmers solely in support of ‘conventional farming’ since the Green Revolution, farmers see economic gains only in high yields promised by “improved/proprietary” varieties.

These hurdles not only lead to sub-optimal in situ innovation with and conservation of agrobiodiversity, but also disincentivize R&D with agrobiodiversity, and/or honest access and use practices. In both instances, the loser – (a) sub-optimal incentives and know-how (education) on why and how to cultivate crops using indigenous seeds and TEK based farming systems, leads to dependence on capital intensive farming that, over time, can lead to severe soil degradation and also progressive economic indebtedness of farmers, and (b) lack of research on and with agrobiodiversity or lack of honest disclosure of source of researched agrobiodiversity, prevents farmers from getting monetary benefits in the form of royalties or ‘benefit sharing’ from any downstream product created as a result of the research, leading to further lack of incentives to continue cultivation with agrobiodiversity. It is also likely that lack of trust and competition among farmers will disincentivize farmer to farmer sharing of indigenous seeds, to the detriment of beneficial spread and region-specific evolution of agrobiodiversity, as well as the erosion of cultures of seed sharing.

The features of blockchain/DLT technology discussed above, can help overcome the issues of lack of trust and traceability (see Annex 3 for an example draft framework within which this can potentially be done). However, to provide stronger economic incentives for in situ innovation with agrobiodiversity and associated research, it is necessary also to link blockchain technologies, not only with automated payment systems, but also automated (monetary) reward systems.

In this context, it is necessary, at the outset, to distinguish digital currencies from cryptocurrencies (commonly linked with blockchain). Currencies, including digital currencies, are essentially a medium of storing and trading ‘value’. In fact, digital currencies are already very much in use in several (or even most) parts of the globe. These digital currencies exist in two forms: in the form of digital payment systems (such as credit cards), and in the form of digital reward points (such as airline mileage points, grocery and other marketplace purchase points or customer loyalty points, all of which are examples of digital currencies that are then used to purchase other products or services, e.g. upgrades on airlines). Cryptocurrencies are not yet in widespread use, but across the globe, several countries have either already embraced them, or are in the process of doing. This is so from a legal as well as technological perspective - Switzerland, for example, is very active in developing and adopting legislation supporting cryptocurrencies. Corporations such as Facebook (albeit under severe legal/regulatory scrutiny and mistrust) recently launched their own cryptocurrency (or ‘virtual money’) based payment system backed (apparently/allegedly) by blockchain technology and the US dollar (to prevent problems of volatility that cause a significant part of the public and regulatory discomfort with the technology).

Leaving aside the uncomfortable topic of cryptocurrencies, it is worth investigating whether blockchain facilitated mechanisms to incentivize research and in situ innovation with agrobiodiversity can be linked with a simpler (non-cryptographic and low energy consuming) automated point granting systems similar to the "carbon points" system that can support what is commonly known as "carbon trading" or

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166 DeLonge, Miles, and Carlisle (2016).
167 Zhang et al. (2007); Lal and Stewart (1990); Oldeman, Hakkeling, and Sombroek (2017); Bhattacharyya et al. (2015).
169 Research has shown that in regions where improved/uniform seeds become the norm, the culture of seed sharing and seed exchange starts to become less prominent, perhaps because ‘uniform’ (HYV and hybrid) seeds need to be purchased afresh from the market each season and do not give desired yields in subsequent generations of cultivation (F2 onwards). See Kochupillai (2016) 208-212 and 50-63.
170 See also Kochupillai (2019a).
171 Yermack (2015); Allec (2008).
172 Peters, Panayi, and Chapelle (2015); Backo, Palová, and Vejacka; Sanlisoy and Çaloglu (2015).
173 Naughton (2019); Dillet (2019).
"emission trading." Such points can then be used to get real cash from one or more of several possible sources, such as:

(i) established funds like the ‘Gene Fund’ or the ‘Biodiversity Fund’ under various Indian laws,

(ii) from a fund maintained through the collection of a possible ‘biodiversity tax’ from sellers of non eco-friendly (uniform) seeds;

(iii) or, from exchanging points for money from industries that would want to acquire biodiversity points to avoid paying the biodiversity tax. In other words, systems can be put into place that require seed, fertilizer and chemical pesticide industries to pay a biodiversity tax, unless they can show legitimate acquisition of “biodiversity points” from research institutions and farmers engaged in research and in situ innovation with agrobiodiversity. Industries looking to move to more sustainable business models can eventually also become partners (nodes) within any blockchain ecosystem created for incentivizing sustainable seed innovations.

The cash acquired in exchange for biodiversity points (from any of the above sources) can then be put to various uses by those who encash them. For example, farmer communities that obtain biodiversity points in the system can use the cash obtained from exchanging them, for rural community development or to support pension payments for aging farmers. Researchers or the scientific community that gets such points can use the cash obtained from their exchange, for further research supporting the cause of sustainable seed innovations. The points-based rewards system can thus support the institutionalization of productivity claims.

It is necessary to explain here that a smart contract facilitated payment-based system (e.g., a one-time payment, or an automatic payment of royalty to originators of seed innovations, namely, small farmers) must also be supported by a point-based rewards system, because the point-based rewards system creates incentives for downstream users and researchers to use rather than avoid the blockchain facilitated system. The point-based reward system would create incentives to use the system, in two ways: (a) by ensuring that points collected can be exchanged for cash from one (or more) of the above suggested sources, and (b) by permitting the specific contribution of each farmer/farmer community and research institutions to be immutably recorded and known to the rest of the world. Therefore, if any research and innovation with PGRs is done ‘outside’ the system (e.g. through illegally acquired PGRs), neither will the farmer contributor of the PGRs get royalties for sharing, nor will the downstream researchers (whether these be other farmers or scientists) get point-based rewards for (research based or new product development based) value addition.174 Here, it is noteworthy that while blockchain supports anonymization of users if so designed, systems can also be designed that facilitate (limited or conditional) disclosure of identities of contributing parties, if they so desire, or, in case of need (e.g. for purposes of legal enforcement, facilitation of payments/encashment and/or correction of technical glitches).

It is perhaps relevant to note here that in order for the world (including, especially, the small and marginal farmers of the world) to truly benefit from cryptocurrencies or even from a (biodiversity) point based incentive mechanisms facilitated by blockchain technology, it is necessary to re-think and re-understand the meaning of the term ‘value’.175 Blockchain is called the internet of value. Yet, the meaning of ‘value’ is not only broad and context driven, but is also very subjective.176 Indeed, it has been rightly said that “something has value primarily because people believe it has value.” Blockchain as a broader technology (beyond bitcoin) permits the capture, storage, release and trading of value like never before.177 With this understanding, actively engaging with and using this technology under appropriately designed regulations and ethics codes to create applications and infrastructure focused on incentivizing sustainable seed innovations, and creating new markets for agrobiodiversity and plant

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174 For a more detailed explanation of how blockchain can incentivize value creation and value addition to agrobiodiversity, see Kochupillai (2019a).
175 Kochupillai (2019a).
176 Ibid.
177 Ibid.
genetic resources, can lead to very promising results, including enhancing environmental health, small farmer incomes, as well as national GDP.

A preliminary framework recommending a means by which blockchain technology (also together with AI applications) can be deployed for (a) promoting (and economically rewarding) farmer to farmer exchanges of indigenous seeds and (b) incentivizing and funding of a wide range of R&D and other activities (e.g. new product development) on and with agrobiodiversity by all stakeholders (as recommended by SSI 1.0 experts), has been described in Annex 3. This is a very basic and preliminary framework. Further multi-disciplinary research and multi-stakeholder consultations need to be done on this framework to develop sustainable and equitable blockchain/AI solutions that lead to socio-economically and environmentally beneficial sustainable seed innovations by all stakeholders, particularly small farmers.

III Implementing the Three-Pronged Approach: Legal and Ethical Considerations

There is little doubt that all existing legal rules and regulatory frameworks operating in the sphere of agriculture, whether it be seed quality related laws, laws protecting intellectual property, or those preventing unauthorized access and use of (agro)biodiversity, are all established with the best of intentions. In fact, unlike in several other spheres of human activity, these laws were also passed based on the dominant scientific understanding prevalent at the time the law was passed. With the scientific community in a state of flux about what kind of agriculture is truly sustainable (from an economic, socio-cultural, environmental and a continuing innovation perspective), laws and policies governing/managing agriculture and associated seed related innovations must also be revisited. In particular, legal regimes and policies must not inequitably favor one direction of scientific research over and above other (emerging) directions, especially when the latter reinforces ancient knowledge contained in TEK systems and supports sustainable seed innovations.

This segment of the position paper gives an overview of some of the major legal regulations that have inadvertently had a negative impact on sustainable seed innovations, and created an imbalance in the landscape of incentives (see also the introductory paragraphs of Prongs 1 and 3). The section also makes recommendations for amendments to these laws where necessary, and/or discusses how (re)education (Prong 2) and modern technologies such as DLT/Blockchain (Prong 3) can help rebalance the incentive structures within existing laws, to bring about a smooth transition towards sustainable seed innovations. This section also highlights key ethical issues that need to be borne in mind while implementing solutions based on these technologies.

(i) (Agro)Biodiversity Access and Benefit Sharing: Re-assessing and re-organizing regulatory check-posts

The most important international instruments in the field of conservation and sustainable use of (agro)biodiversity are the Convention on Biological Diversity (CBD) (together with the Nagoya Protocol), and, in relation to seed diversity, the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA, also called the “Seed Treaty”). Both instruments seek to promote ex situ as well as in situ conservation of (agro)biodiversity, while also highlighting the importance of establishing equitable access and benefit sharing mechanisms. As discussed above (Prong 3), hurdles associated with lack of incentives (to continue in situ cultivation and innovation with agrobiodiversity) on the one hand, and lack of trust, transparency and traceability vis-à-vis the acquisition and use of agrobiodiversity (and PGRs) on the other, lead country level regulations implementing these international treaties and protocols, to introduce several bureaucratic check-posts with two very well-meaning goals in mind: (i) the prevention of biopiracy, and (ii) ensuring that equitable benefits are shared.

178 Robinson (2014).
with communities who share their PGRs and associated know-how. What we witness, however, is that despite these bureaucratic check-posts, little to no benefit sharing activity is ongoing. 

According to experts, the contributions to the Gene Fund established under the PPV&FR Act, as well as funds collected by the Biodiversity Authority, are negligible if not non-existent. It is necessary to look carefully into the reasons for this and to determine whether these check-posts might be acting as hinderances rather than as means of facilitating beneficial exchange, and what impact these hinderances are having on balancing out (monetary) incentives for research and in situ innovation with agrobiodiversity. Essentially, any check-post established under the biodiversity law and/or the PPV&FR Act must:

(i) Ensure that no biodiversity (PGRs) leaves the possession of those who are contributing it, without the consent of the contributors, payment of a proper price (commensurate with the intended end use) and guarantee of traceability of downstream uses and sharing of benefits resulting from such use; and

(ii) It must also ensure that those who are seeking PGRs in return for fair benefit sharing, do not get disinterested or disillusioned by excessive red tape.

Within Indian as well as international legal frameworks associated with the protection of (agro)biodiversity and benefit sharing, several amendments may be necessary to make the current check-posts more mutually beneficial for contributors and users of PGRs. First, to the extent that check-posts under existing regulations (such as under the Biodiversity Act and the PPV&FR Act) have failed to create atmospheres of trust and facilitate mutually beneficial transfers and exchanges of biodiversity and associated genetic resource, it is worth exploring DLT/Blockchain technologies (as discussed in Prong 3) that are created with the aim of resolving problems of lack of trust via automation and via a shift of trust into the hands of those that are more trusted by local/rural communities. These technologies can also be used to automate payments using smart contracts, and to award points/tokens to incentivize research aimed at supporting or adding value to sustainable agriculture using indigenous/heterogeneous seeds and TEK based farming systems. This would incentivize mutually beneficial transfers of agrobiodiversity and PGRs contained therein, while also cost effectively facilitating quality checks to support indigenous seed sales by small farmers. However, the manner in which these technologies are structured need careful consideration and must be backed by ethical codes as well as concrete regulation. These are discussed in the last sub-section hereunder.

However, before the DLT/Blockchain based solutions are implemented, some key amendments to international legal instruments and corresponding national laws are recommended:

**Disengage Benefit Sharing for PGR Access from Downstream IPR Protection**

In the context of the Seed Treaty (and the Indian PPV & FR Act, 2001), it is necessary to re-think the current legal provisions that mandate benefit sharing only if the downstream research with PGRs is protected by intellectual property rights. It may be possible to justify this current limitation if we start with the outdated scientific understanding that the Mendellian “genes for traits” (and associated management of soil and water so as to keep them as uniform as possible) approach is the only way to accomplish food (and nutritional) security. In other words, under this older scientific understanding, it was (and in several pockets, it is still believed) that uniform varieties are better and more necessary for food security than heterogeneous, non-uniform varieties. If this is the understanding we start with, the rationale behind granting a share of benefits to farmer-contributors of

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179 Prip and Rosendal (2015); Kamau, Fedder, and Winter (2010).
180 Dutfield (2002); Tsioumani (2018).
182 Chen (2019); Baker, Jayadev, and Stiglitz (2017).
184 Charnley and Radick (2013); Jamieson and Radick (2017); Jamieson and Radick (2013); Radick (2016); Radick (2016).
185 Sperling and Cooper (2004); Blakeney (2009).
PGRs only if downstream improved seeds are protected by IPRs, seems to be as follows: in exchange for contributing PGRs, farmer-contributors of PGRs (eventually) get access to “improved” seeds that are not protected by IPRs, and this is “benefit sharing” enough, because (at least hypothetically speaking), farmers can then save seeds from season to season and save costs associated with buying proprietary seeds from the market each season, or can compensate for seed costs by getting much higher yields (and therefore, higher profits) than they could with indigenous heterogeneous seeds.

However, there are other facts, backed by growing scientific and empirical research, to be considered here, namely: (a) “improved” seeds do not work well in marginal environments, not least because breeders rarely focus their research in resource poor areas. More specifically, they do not work well without external (chemical) inputs that stabilize the environment in which they are cultivated; (b) “improved” seeds that are “uniform” and rely on chemical inputs for their performance, have a negative impact on the environment and are not sustainable in the long run; (c) cultivation with “improved” seeds that rely on chemical inputs is not economically profitable for farmers (especially small and marginal farmers, who often incur heavy debt to acquire these inputs); and (d) “improved”/uniform seeds lead to erosion of socio-cultural diversity associated with locally relevant crops and food. Therefore, the benefits obtained by small farmer contributors of PGRs, even in cases where the “improved”, uniform seeds are not protected by IPRs, is not commensurate with the economic benefits derived by corporations or research institutions that utilize these PGRs. In fact, the “exchange”, if any, in these circumstances is a bad deal for farmers and the environment alike.

On the other side of the spectrum, as discussed at the start of Section II of this position paper, indigenous seeds do not (and are not engineered to) perform well in the presence of chemical fertilizers and pesticides. A farmland that adopts “uniform” seeds and “uniform” soils treated with chemical fertilizers and pesticides, is therefore likely to show reducing/diminishing yields when attempting (to go back to) using indigenous, heterogeneous seeds. Accordingly, once farmers have “converted” to conventional farming using uniform, “improved” varieties, they need monetary resources and economic incentives to go back to sustainable farming methods. These monetary incentives are necessary, at first instance, to re-balance the landscape of incentives vis-à-vis engagement with conventional versus traditional/sustainable farming informal. More concretely, these monetary incentives/supports are necessary for small farmers to meet the costs involved in converting their conventional farms back to organic/natural farms. Costs are involved here because heterogeneous seeds need heterogeneous soils, i.e., soils that are rich in microbial diversity, as well as other biotic diversity that offers much needed ecosystem services. Accordingly, re-conversion of “conventional”/chemically treated farms, back to natural/organic farms rich in such diversity, requires several months or longer. In the interim period, farmers will still have to face low quality and/or quantity of harvest, to overcome which, monetary support/incentives (in addition to insurance coverage or other subsidies/compensations) are necessary.

Farmer custodians of agrobiodiversity are not just stakeholders, but indispensable partners for the long-term continuation of formal innovations by the public and private sector seed, fertilizer and pesticide industry. Ethics, equity, economics as well as common sense, therefore, dictates that farmer-contributors of PGRs get royalties in addition to significant initial (bulk) payments for sharing their PGRs. By incentivizing in situ agrobiodiversity conservation and improvement through adequately long-term benefit sharing with small farmers, such that both on-soil (crop/seed) and in-soil (beneficial microbial) diversity is protected and enhanced, the research community as well as the private sector (breeders and

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187 Azadi and Ho (2010); Krimsky and Wrubel (1996); Wiseman and Hopkins (2001); Jacobsen et al. (2013).
188 Wiseman and Hopkins (2001).
189 Jacobsen et al. (2013); Patra et al. (2016).
190 Ellen and Platten (2011); Vià (2012); Bèye and Wopereis (2014).
192 While further research is needed to confirm this, anecdotal evidence from farmer interviews and observations made during empirical research, suggests such trends. See Kochupillai, (2016) 87.
corporations), would also benefit in the long run.\textsuperscript{194} How and why this is the case, has been discussed in Section IV below.

Accordingly, it is necessary to re-think current laws limiting benefit sharing for PGR access only to cases where the downstream varieties (resulting from the use of PGRs), are protected by IPRs\textsuperscript{195} or are utilized in a hybridization program.\textsuperscript{196}

**Benefit Sharing for Access to Soil Microbial Diversity from TEK Based Farming Systems**

Looking beyond seeds, towards whole sustainable systems of agriculture (see Prong 1), it is noteworthy that for long term food and nutritional security, incentives and monetary benefits must be secured not only for farmers cultivating locally relevant indigenous (heterogeneous) seeds. Incentives and monetary benefits must also accrue to (a) those (farmers/communities) who generate and share knowledge and information about how best to cultivate such seeds in specific local conditions, in the presence of specific types of biotic and abiotic stresses, to get best results (including yields, quality etc. See for example, Box 2: Jitul’s Story), and (ii) those who generate and share knowledge/information about how to optimize beneficial microbial populations within specific soil types and vis-à-vis specific crops.\textsuperscript{197}

In this context of in-soil microbial diversity also, the principles and spirit of the CBD and the Nagoya Protocol can perhaps be better accomplished with the help of DLT/Blockchain based solutions, coupled with AI/Machine Learning solutions. The scientific understanding of the relevance of in-soil microbial diversity (rhizobial bacteria\textsuperscript{198} microbiomes\textsuperscript{199} and holobionts\textsuperscript{200}) and their interaction with plant roots and root bacteria has evolved considerably in recent years.\textsuperscript{201} According to Prof. Gary Bending (University of Warwick), an expert on soil microbiology:

 Plants have co-evolved with diverse microbial communities which are key determinants of plant health (Hassani et al, 2018). This ‘microbiome’ is recruited from microbes associated with seeds and from the soil in which the plant is growing. While some members of the microbiome are pathogens, others are mutualists and promote plant growth through numerous direct and indirect mechanisms. Plant genotype exerts influence on composition of the microbiome and its specific functional attributes. Evidence suggests that domestication of crops has resulted in a fundamental shift in the plant microbiome including the loss of some key functional groups (Perez-Jaramillo et al., 2018). This is likely associated with the breeding for plants adapted to agricultural systems which rely on maintenance of high soil fertility using fertilisers, and the loss of microbial groups which maintain plant health in natural and low input systems.

There is currently great interest in developing sustainable farming systems in which the plant microbiome is utilised to support plant nutrition and health, replacing use of fertilisers and pesticides. This may include manipulating the microbiome through crop genotype, or by using microbial inoculants with specific functional traits. Wild genotypes and cultivars adapted to low input systems are vital tools for the development of these resources.\textsuperscript{202}

Therefore, it is not just the commercial potential of PGRs that is growing, but also the commercial potential of soil microbial communities associated with specific crops and crop species that can be used

\textsuperscript{194} See also, Kochupillai (2016) 9-13.

\textsuperscript{195} Ho (2010); Food and Agriculture Organization of the United Nations (2019).

\textsuperscript{196} Plant Variety Authority India (2019).

\textsuperscript{197} Dawoe et al. (2012); Barrios et al. (2006), ibid.; Chaparro et al. (2012).

\textsuperscript{198} Lindström et al. (2010); Prashar, Kapoor, and Sachdeva (2014); Bever, Broadhurst, and Thrall (2013); Berendsen, Pieterse, and Bakker (2012).

\textsuperscript{199} Van Der Heijden, Bardgett, and Van Straalen (2008); Vandenkoornhuyse et al. (2015).

\textsuperscript{200} Andreote and Silva (2017); Cernava et al. (2017).

\textsuperscript{201} Jha and Saraf (2015); Velmourougane, Prasanna, and Saxena (2017).

\textsuperscript{202} Email correspondence from Prof. Gary Bending dated 14 July 2019.
to create microbial rather than chemical fertilizers.\footnote{Hilton et al. (2018); Thompson et al. (2016); Elias et al. (2017).} It also appears likely that soil microbial populations that get optimized with TEK based farming systems (See Prong 1) may be unique to each location and to each crop.\footnote{Bokulich et al. (2016); Sbabou et al. (2016).} Soil systems that are linked to TEK based farming systems are therefore like potential goldmines, provided systems are put into place that allow their ‘value’ to be appropriately captured and benefits derived therefrom, equitably transferred to farmers and farming communities.\footnote{To understand the concept of ‘capturing’ value in soil and seed diversity, see Kochupillai (2019a).} Blockchain/DLTs, (together with AI applications) can facilitate secure and ‘controllable’ data sharing by farmer-generators of information/data, while ensuring fair, inclusive and equitable economic benefits for those sharing data\footnote{Swan (2015); Maru et al. (2018).} (In this context, see also Section IV and Annex 3 hereinbelow).

If this information/data/know-how, once shared, were to generate monetary benefits for farmers contributing it, an equitable, sustainable and mutually beneficial system can be created. As of now, as discussed above, attracted to the ‘high yield’ promise, farmers abandon ‘high value’ cultivation\footnote{Kochupillai (2019).} choices that are better for the environment and also better for their own long-term socio-economic prosperity.\footnote{Shiva (2016); Kyeyune and Turner (2016).} India should therefore closely consider supporting the move to bring ‘digital sequence information’ associated with biodiversity originating in India, within the scope of the Nagoya Protocol.\footnote{Kupferschmidt (2018).} At the same time, however, it must also be borne in mind that if this move is made without the parallel adoption of concrete means (such as DLT/Blockchain based solutions) that support the legitimate and traceable transfer of such digital information, it may lead to a slow down of globally beneficial research\footnote{Mitchell, Johnston, and Bassel (2016); Engl (2019).} or an increase in illegal/inequitable transfers of information.

\subsection*{(ii) Plant Variety Protection and Farmers’ Sustainable Innovations with Agrobiodiversity}

As discussed above, farmers’ indigenous/heterogeneous seeds are not appropriate candidates for protection under existing intellectual property protection regimes (especially plant variety protection regimes), even when these are selected and improved in specific local conditions. Their inherent genetic variability makes them non-uniform and this non-uniformity is their greatest asset. Yet, this genetic variability makes them ineligible for plant variety protection certificates that require applicants to ensure that their plant varieties fulfil the so called DUS requirement. Under the DUS requirement, the variety that is seeking registration must be ‘Distinctive’, i.e., it must be distinctive from other varieties, must be ‘Uniform’ and must be ‘Stable’.

In other words, PVP regimes leave little room for indigenous varieties that are by their very nature variable and non-uniform to be considered for PVP protection. More importantly, even if they were to be registered, indigenous/heterogeneous seeds would not enjoy any meaningful protection as it would be difficult to detect infringement based on any declared phenotypic characteristics, as the phenotype of such heterogeneous/indigenous seeds would vary from location to location and depend on soil health, biotic and abiotic conditions.\footnote{Bishaw et al. (2019).}

With intellectual property protection regimes being designed to protect and incentivize R&D in uniform varieties, and governmental policies recommending frequent seed replacement via market purchase of such seeds, economic incentives, again, shift away from cultivation of non-uniform, indigenous seeds using farming systems that promote seed and soil health and diversity.\footnote{Kochupillai (2016), 145-47.} Again, therefore, in order to rebalance the incentives landscape\footnote{Ibid.}, an equitable transfer of monetary benefits (in the form of initial
bulk payments as well as % of profits/royalty payments) must be ensured in each instance of PGR (or soil microbial diversity) transfer.

In the absence of underlying statutory provisions mandating such royalty payments, PGRs shared by any farmer or community must be seen as a transfer of know-how/knowledge or as a transfer of data (and not as a transfer of ‘materials’). Further, such transfers must always be done under written contracts, where under, the royalties must be payable for the ‘term of the contract.’ Current intellectual property and PVP laws that do not grant IP rights to indigenous/heterogeneous materials might need to be amended to require such royalty payments (or ‘terms of contract’) to last for at least as many years from the date of ‘sharing’, as IP protection over a corresponding ‘improved’/uniform variety would have lasted if IP protection were applied for and granted.

Of course, one might argue that this written contract-based transfer is already what is required under biodiversity protection and PVP laws. However, as the implementation of such laws is problematic (as discussed above), and meaningful IP protection does not exist for indigenous/heterogeneous materials, again, a blockchain/DLT solution may be necessary and useful in facilitating automated contractual agreements and payments of micro-royalties through deployment of ‘smart contracts.’

The adoption of such automated mechanisms must be supported by necessary amendments to the PVP and Biodiversity protection laws.

Further, it is noteworthy here that negative externalities and market failures resulting from the increasingly widespread adoption of formally improved seeds that comprise primarily of uniform varieties, are currently not accounted for in the price of these seeds and planting materials. Accordingly, the imposition of a kind of a ‘Piguvian Tax’ (previously referred to herein above as a possible “biodiversity tax”) on “uniform” seeds should be considered on priority by the Government of India. As discussed under Prong 3 above, the money collected through such a taxation scheme can then go to those who get automated token/award points for conducting research on/with agrobiodiversity/PGRs, not least because such research enhances the ‘value’ of the PGRs and the agrobiodiversity in which they are contained.

(iii) Seed Certification, Safety and Efficacy: Re-distributing responsibilities and rewards

India’s Seeds Bill that has been pending since 2004, aims to establish certain systems that can facilitate the emergence of regional, national as well as international markets for indigenous/heterogeneous seeds. For example, the mandatory seed certification requirement can help farmers and farmer groups get their varieties quality tested and also help them get a brand/denomination for their locally unique seeds. However, this mandatory seed registration requirement has been opposed by farmers and farmer groups because it can create a heavy bureaucratic and financial burden on them. Accordingly, the pending Seeds Bill, based on the recommendations of the last Standing Committee Report, while seeking to make varietal registration mandatory, still excludes farmers’ varieties from mandatory registration and certification.
Permitting farmer level (collective) branding of indigenous (local) seeds

However, the Bill then also bans farmers from selling branded seeds; farmer to farmer seed sales and exchanges can only take place in brown bags devoid of brands or other means of recognizing their source.\textsuperscript{225} This mandate counters the ideal of traceability and also prevents the emergence of robust and profitable markets for heterogeneous/indigenous seeds. It is also contrary to the recommendations of farmers and their representatives in the SSI 1.0 working groups, which recommended that all indigenous seeds get a unique name/brand, inter alia, to facilitate traceability to their source (see Annex 2), and help other farmers recognize trustworthy indigenous seed suppliers from among other farmers in the village or region.

Here again, therefore, to tackle the problem of affordability and feasibility of registration, while still giving farmers and farmers’ association the right to (collectively) brand and sell their seeds if they desire, DLT/Blockchain solutions can be extremely beneficial. Such solutions support decentralization of the registration process, while also giving incentives to any/all persons with the requisite know-how, to add ‘value’ to the chain of transactions and the underlying product, by conducting necessary tests and reporting/uploading the results on to the blockchain/Digital Ledger.\textsuperscript{226} As discussed in Prong 3 and Annex 3, such entities can be government agencies or private sector companies that are ‘nodes’ on the blockchain architecture. Once they add ‘value’ to the indigenous seeds by conducting necessary tests on them to determine safety, quality etc., they can automatically be awarded tokens/points by the DLT/blockchain/smart contract system. These tokens/points can be exchanged for cash from the funds collected via the biodiversity tax, or from the Gene fund/biodiversity funds, or by trading on the open market (similar to carbon/emissions trading). In fact, blockchain applications are already being used to facilitate carbon trading.\textsuperscript{227} It is noteworthy here that blockchain architectures adopted for providing these solutions need not trade in cryptocurrencies. Moreover, they also need not (and must not) be 100% private; governmental participation through all relevant and currently existing governmental authorities is mandatory to ensure a smooth, sustainable and legally accountable system. In fact, the Seeds Bill, 2004 “requires every person in the value chain to keep track of the preceding person, so that a faulty lot can be withdrawn.”\textsuperscript{228} In such situations, to eliminate any chance of corruption or human error, and also to increase accountability, DLT/Blockchain technologies are not only useful, but may be necessary to ensure meaningful and accurate traceability. At the same time, it is necessary for any established system to be first tested at a very small scale and then slowly expanded if pilot projects are found to be successful.

Re-thinking ‘uniformity’ and ‘genetic purity’ requirements under planned Seeds Act

It is also necessary that the registration requirement under any enacted law does not mandate standards of safety and efficacy (such as genetic purity) that are no more considered valuable in all circumstances, and especially not in marginal environments that do not utilize chemical inputs.\textsuperscript{229} For example, to the extent that the Seeds Bill mandates “genetic and physical purity” of seeds and specific prescribed ‘limits of variability’, it is worth looking into emerging scientific evidence that recommends using genetically diverse seeds (rather than uniform varieties) for sustainable agriculture.\textsuperscript{230} In this context, it is also relevant to note the provisions of the new EU Regulation on Organic Production and Labelling of Organic Products, adopted in 2018 (the new EU Organic Regulations or the EU Regulation). The EU Regulation permits and encourages, inter alia, the use in and marketing for organic agriculture of “plant

\textsuperscript{225} Trademarks and brands support source recognition, which helps customers distinguish between good and bad sources. This helps customers choose which source to rely on for good quality products/services or for goods and services that meet their unique needs. Murdoch, Marsden, and Banks (2000); Moschini, Menapace, and Pick (2008).

\textsuperscript{226} Wang et al. (2019)

\textsuperscript{227} Chokshi et al. (2018); Fu, Shu, and Liu (2018); Khaqqi et al. (2018).

\textsuperscript{228} Parliamentary Research Service India (2004).

\textsuperscript{229} Altieri and Nicholls (2012), 42; Jovovic and Kratovaleva (2015).

\textsuperscript{230} See also discussion under Prong 1 above; Gruber (2017); Thrupp (2000); Esquinas-Alcázar (2005); Jacobsen et al. (2013).
reproductive material of organic heterogeneous material.” Such heterogeneous materials do not need to fulfill the registration and certification requirements under various EU laws.231

The EU Regulation clarifies that ‘heterogeneous materials’, unlike current proprietary seeds, need not be uniform or stable, and notes based on “Research in the Union on plant reproductive material that does not fulfill the variety definition... that there could be benefits of using such diverse material... to reduce the spread of diseases, to improve resilience and to increase biodiversity.” Accordingly, the regulation removes the legal bar on marketing of “heterogeneous materials” and encourages its sale for organic agriculture, thus clearing the way for more expansive use of indigenous varieties. As was stated elsewhere, “Once the delegated acts under the EU regulation are formulated, they will support the creation of markets, especially markets and marketplaces facilitating trade of heterogeneous seeds, including by small farmers who are currently the most active in maintaining and improving such seeds in situ. Indeed, multimillion-Euro research and innovation projects being invited and funded by the EU already aim to make this diversity a more integral part of farming in Europe. And here they are talking only of the diversity within Europe.”

Needless to say, a market for ‘uniform’, non-variable varieties can continue to exist. What is necessary, however, is to permit, in parallel, ‘True Labels’ that declare the fact of heterogeneity and variability, together with the specific benefits and characteristics the cultivation of such seeds brings to farmers and the environment. Supported by digital traceability, distributed (rather than centralized) certification systems, and smart-contract based micro-payments and biodiversity token/points awards, the parallel emergence of a market for heterogeneous materials can be facilitated, especially for use in organic or traditional agriculture, and for both environmental and economic benefits for small farmers. This would permit the emergence of healthy and diversified markets for heterogeneous/indigenous seeds, managed by small farmers with the help of various ‘nodes’ in the DLT/Blockchain solution. Such facilitating solutions would encourage small farmers and farmer communities to become entrepreneurs, supporting the overall growth of the Indian agricultural economy, while also helping India become a world leader in providing indigenous, heterogeneous seeds of high quality, adaptable to very diverse small farm conditions, to farmers all over the world.

(iv) Rolling out DLT/Blockchain Solutions: Ethical Issues to be considered by emerging regulations

As discussed in Prong 3 above, blockchains/DLTs are essentially platforms that help manage data, and when designed and governed using appropriate models, can help solve problems of trust, traceability and equitable data collection, storage and use. Blockchain/DLT can also support and facilitate payments (including royalty payments) of equitable compensation to those sharing their data. Blockchains can be public or private (or a combination of public and private), based on the type of architecture and governance model they adopt. Appropriately designed models can empower data providers to collectively track, control and monetize the usage of their contributed data and assets.

In particular (and summarizing Prong 3), such systems can help by (a) maintaining an immutable record of transactions/transfer of agrobiodiversity from farmers to various categories of end users; (b) collecting data about the agrobiodiversity transferred, such as unique cultivation methods, special characteristics etc.; (c) securing/protecting the data through the deployment of technologies such as multi-level hashing and encryption, thereby also helping ensure that the contributors and transformers of data can retain control over who can use the data, how and when it can be viewed or accessed; (d) structuring the data to be used in various AI solutions in a manageable form, and; (e) facilitating automatic transfer of monetary benefits for the contributors of data, especially from their use in diverse applications, thereby effectively incentivizing continuous cultivation and engagement with agrobiodiversity.

231 European Parliament and the Council (2018); Schmidt (2019); Turpin (2018); Fuss et al. (2018); Feher et al. (2019).
232 Kochupillai (2019); Wezel et al. (2018).
Data managed by blockchain/DLTs, can be connected to machine-learning based AI applications to be used by farmers and researchers in search of solutions to area-specific (i.e. disciplinary or geographic area-specific) problems. What types of data can be stored and managed by blockchains and how these can be then transformed for usage by AI solutions needs further multi-disciplinary research from technical standpoints. For the purposes of this Position Paper and this section, we focus on ethical issues that any technical solution and legal regulation linked with such technical solutions must bear in mind.

**Ethics, Data & Blockchain**

Data is increasingly considered a tradeable commodity, the transfer/sharing of which needs to be regulated to facilitate its beneficial use in various emerging technological applications, the most prominent of which are AI/Machine Learning applications. With growing economic & political relevance of data, several major ethical issues linked to its use are also surfacing. Platforms that adequately address these issues are indispensable to the meaningful & widespread adoption of (AI) applications that rely on data to design solutions for any specific sector/use case. As discussed above, DLTs/Blockchain can potentially help address several of these ethical issues, including issues of (a) trust and privacy; (b) secure and “controllable” data sharing; (c) fair, inclusive and equitable economic benefits for those sharing data, and (d) traceability (for purposes ranging from economic benefit sharing to liability determination). Yet, any blockchain/DLT solution that is adopted, can lead to additional or new problems, unless it incorporates “ethics-by-design”, i.e. it incorporates a design/architecture that takes not just existing legal and regulatory regimes into account, but also considers ethical concerns that are commonly linked to technological or automated solution. Some of the key ethical issues that any blockchain based solution/platform, as well as any law or policy seeking to regulate it, must bear in mind, include:

(a) Trust and privacy. While AI+blockchain/DLT solutions can help address issues of trust (as discussed above), they might also create new issues of trust, including trustworthiness of codes governing smart contracts and trustworthiness of persons and institutions running nodes on a blockchain. At the same time, privacy (and security) of those participating in the system are a concern particularly in rural set ups where enforcement of law and order can be challenging, especially in situations where emerging technologies are viewed as likely to (at least partially) disrupt existing socio-economic power structures.

(b) Fairness, bias and inclusion. As discussed above, it is envisaged that AI+Blockchain can help overcome barriers inadvertently created by current regulatory thickets. However, as code and machine learning based systems have their own limitations and can result in the development of new types of unintended biases and exclusions, checks and balances need to be built into any AI+blockchain system aiming to equitably promote research and in situ innovation in agrobiodiversity by all stakeholders (farmers, researchers and breeders). Further, empirical research is needed to identify what is considered ‘fair and inclusive’ by contributors (farming communities), vis-à-vis the use of agrobiodiversity by downstream players and fair remuneration/royalty for accessing the same. Questions such as the period of time for which royalty must be payable following a transfer of PGRs, the % of royalty, the means by which this royalty is to be utilized (e.g. will it be only for individual farmers or for farmer communities, and the funds can therefore be used for community development), are all questions that relate to the ethical issues of fairness, bias and inclusion. Inclusion vis-à-vis such technologies is also a matter of making sure that equitable access to hardware (smart phones) and internet is available to small farmers, not just in specific regions of India, but across all regions. This would need, for example, the focus of subsidies to shift or be re-distributed to cover not just fertilizer subsidies, but subsidies for acquiring the necessary hardware and internet access.

(c) Transparency (including explainability) and traceability. Transparency vis-à-vis sources from which data is collected and the end uses to which it is put, is crucial to building trust in the

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system and ensuring its long-term usability. While blockchain/DLT solutions enhance transparency and traceability to source vis-à-vis digital data, they are only starting to be appended to AI and IoT devices to permit traceability of physical goods.\(^{234}\) In case of seeds and soil microbial diversity, which are sourced with the aim of further transformations, in order to make the traceability meaningful, they would need to be combined with biomarkers, DNA barcodes etc. Ethical and multi-disciplinary issues linked to such technological combinations will need to be investigated.

(d) Governance, regulation & sustainability: With AI & blockchain technology replacing human actors, it would be necessary to ensure smooth interaction between existing governance structures & regulations on the one hand, and emerging AI/blockchain based technological solutions on the other, to ensure a sustainable and seamless transition that maintains and secures meaningful and continuing interaction between human and autonomous actors. In this situation, one of the key questions that would emerge would be: What kinds of organizational and leadership models/structures can support synergistic interactions between human actors (in current regulatory regimes), and autonomous actors (codes) in planned AI+blockchain applications to enhance trust, promote equitable benefit sharing and ensuring responsible decision making? From a more practical standpoint, it would also be necessary to determine which government agencies, NGOs and private players would need to be ‘nodes’ in the blockchain and whether public permissioned / public permissionless (or other) architectures would be better suited to enhance trust and secure privacy in the AI+blockchain facilitated system adopted for the purpose of promoting sustainable seed innovations? With the emergence of “code” based governance, it is also necessary to see how issues of liability would be reconciled. Finally, in a country as diverse as India, fair and inclusive DLT/blockchain governance models must take cultural diversity, equity, and practical usability into account, supporting the development of ethical business models for the benefit of farmers, researchers and the environment.

Of course, the benefit of any distributed DLT or Blockchain technology increases with the number of players (nodes) and contributors (users); the greater the number of nodes, i.e. those who are engaged in contributing or testing seeds, soils, cultivation methods etc. on a blockchain, the higher the chances that any user of the system will be able to get an accurate view of the quality of the products being offered via the blockchain facilitated marketplace. In order to ensure that the system is not overtaken by vested interests also, a large number of players (farmers, researchers, end consumers, government bodies etc.) must be a part of the blockchain network.\(^{235}\)

Annex 3 herein below, suggests a very preliminary outline for a blockchain/AI based framework to promote sustainable seed innovations. However, extensive multi-disciplinary research and multi-stakeholder consultations are needed to build up to a complete workable architecture before it can be rolled out. What must be underscored, however, is that emerging technologies such as Artificial Intelligence and Blockchain can and should be given adequate research as well as policy level/regulatory attention. Also, to the extent that these technologies aim to bring benefit to the poorest and most marginalized segments of society\(^ {236}\) and hold the potential to incentivize research and innovation in thus far neglected areas,\(^ {237}\) it may be more beneficial to invest in researching these technologies thoroughly and deploy them under comprehensive legal and ethical rules, rather than rejecting or limiting their potential scope of application and utility.

It is noteworthy in this context that while blockchain technology can support private ordering and self-governance by the blockchain ecosystem, in fields as sensitive and important as agriculture, blockchain

\(^{234}\) Kamath (2018); Imeri and Khadraoui (2018); Agrawal, Sharma, and Kumar, (2018); Lin et al. (2018); Xu et al. (2019).

\(^{235}\) For further details, including a better explanation of why multiple players make a blockchain/DLT solution better, please see Annex 4 below.


\(^{237}\) Kochupillai (2019a); Hericko; Ribitzky et al. (2018); Beck and Müller-Bloch (2017); Iansiti and Lakhani (2017).
codes and codes governing smart contracts must not be privately ordered. However, semi-private ordering of codes, after consulting farmers, NGOs, scientists and government agencies would be the best way forward. This can entail the creation of ethical codes via multi-disciplinary research engaging all stakeholders in consultations; or self-regulation by farmers supported by broad legislative guidelines and regulatory check-posts (e.g. mandatory government body nodes in any blockchain architecture created for promoting sustainable seed innovations).

IV Looking Ahead: Diversifying Research Goals and Directions of Data/Knowledge Flow for Sustainable Seed Innovations

This concluding section highlights why the diversification of research goals and of directions of data/knowledge flows, are necessary for sustainable seed innovations in the present and future. This section highlights certain global trends and statistics to underscore why sustainable seed innovations are likely to become increasingly relevant in the coming years, not only for environmental and socio-cultural sustainability, but also for making agriculture’s share in the Indian economy significantly stronger and more prominent. The role of small farmers, and of those (farmers, researchers, NGOs and corporations) engaged in research and in situ innovations with agrobiodiversity, is crucial in this regard. To equitably support and incentivize them to work in the direction of sustainability, India needs to embrace insights from its own traditional knowledge-based farming systems, as well as the latest technologies, both together.

A Global Trends in Agricultural Research Funding

Agroecology is a farming system that is conceptually similar to TEK based farming systems. In fact, published literature has referred to the now famous “Zero Budget Natural Farming” as a movement in agroecology. TEK based farming systems have been known, used, re-discovered and have evolved over centuries. Agroecology, on the other hand, was ‘rediscovered’ around the same time than genetic engineering came up. Yet, while the latter (biotechnology) has developed into a specialized science that receives millions of dollars in annual research grants from various sources, the former has received only marginal attention, rarely being covered by scientific research or scientific research funding. This fact already evidences the existing imbalance in research focus and research funding – capital intensive subject matter that mandates (large) industrial involvement for further development into products, receives the bulk of the attention and funding.

A study in the United States investigated projects that were registered in 2014 at the USDA Current Research Information System (CRIS) database with a focus on sustainable agriculture, including agroecology. Of all registered research within agriculture (including all types of agriculture), 18-36% of the studies analyzed reduced, more efficient inputs, 24% of the studies analyzed more sustainable inputs & practices, 13% investigated ecological principles, and 14% the social dimension of agroecology. Within the USDA, very little funding (4%) flowed into studies that focused on more integrated approaches (e.g. by combining social and ecological principles). Only 1% of the funding was invested in integrated crop-livestock systems and less than 1% of the funding flowed into agroforestry. Further, the research does not target solutions, instead, the focus is on finding means of mitigating negative ecological and social consequences of the existing system (e.g. impact on health). These trends suggest, once again, the current imbalance in research focus and funding. In fact, it also reveals that what is today called “conventional farming” is considered to be inevitable and despite increasing recognition of

238 Altieri (2018); Kremen, Iles, and Bacon (2012); Berkes, Colding, and Folke (2000).
239 Khadse et al. (2018); Rosset and Martínez-Torres (2014); Rosset and Martínez-Torres (2013); Mier y Terán Giménez Cacho et al. (2018).
240 Altieri (2004); Altieri and Nicholls (2017).
241 Vanloqueren and Baret (2009).
242 Yu (2007); Müller (2002); IndiaBioScience.org, (2019); Government of India (2019).
243 Vanloqueren and Baret (2009).
244 DeLonge, Miles, and Carlisle (2016).
its negative impacts, the only thing research can do is to attempt to mitigate these negative impacts. Any alternative solutions are often considered unrealistic.\textsuperscript{245}

Further, global studies analyzing public and private research funding on different agriculture methods found that only around 1-5\% of the budget for research on food and farming is spent on research on organic methods.\textsuperscript{246} For Europe, the Research Institute of Organic Agriculture (FIBL) estimated the annual spending of the European Union on organic food and farming systems at only 3-11\% of the total agriculture budget between 1998 and 2013.\textsuperscript{247} It must be noted here, however, that from a global perspective, there is only little comprehensive information or statistics available. Nonetheless, in the context of global public research, it is well known that the major share of public research funds flow into projects fostering conventional and industrial methods such as biotechnology.\textsuperscript{248} More interestingly, the limited funds that do flow into organic research, often apply the same research goals as conventional farming, namely aiming for efficiency, and enhanced productivity through yield optimization.\textsuperscript{249} Here we notice once again the imbalanced landscape of research funding – the focus is on “high yields” rather than on “high value”\textsuperscript{250}, even in systems of farming that claim to be focused on sustainability and environmental protection.

Undoubtedly, the focus on ‘yield’ is a direct result of the need to have ‘food security’. Yet, a lot is lost with this focus on high yield and food security: loss of nutritional security,\textsuperscript{251} loss of biodiversity,\textsuperscript{252} loss of socio-cultural diversity and sense of connection with local traditions and festivals,\textsuperscript{253} and increasing loss of interest in, and respect for agriculture as a profession (resulting in increasing rural urban migration and various associated problems).\textsuperscript{254} In fact, as discussed above (Prong 3), the specific approach dominantly adopted to increase yield (i.e. a focus on adoption of ‘uniform’ seeds that rely on the genetic make-up of seeds and chemical inputs to keep the environment also as uniform as possible – see prong 2), also leads to a skewing of the landscape of incentives to innovate. This is not only because intellectual property protection regimes (particularly patents and plant breeders’ rights) only (effectively) incentivize innovations by the formal sector, but also because agricultural policy since the Green Revolution has pushed for a top-down model of innovation and information flows.\textsuperscript{255}

The imbalanced research funding landscape creates a skewed landscape of scientific knowledge.\textsuperscript{256} For example, studies have shown that a major knowledge gap exists especially vis-à-vis the quantification of costs of agricultural production systems\textsuperscript{257} in the area of eco-functional intensification of agriculture,\textsuperscript{258} and also in the area of ecosystem services.\textsuperscript{259} The threat of climate change that human existence is faced with should make this research and knowledge gap, not just surprising, but perhaps also alarming. This imbalanced and skewed scientific knowledge landscape leads to an imbalanced educational curriculum, starting a vicious cycle that prevent future scholars and researcher from studying more integrated, holistic ways of farming (see also Prong 2). Take again, as an example, the case of agroecology: There currently exists a wide variety of views of what exactly comes within the scope of ‘agroecology’. Due to a lack of research funding available for studying agroecology, a widely accepted definition of

\begin{itemize}
\item Smith et al. (2013); Bommarco, Kleijn, and Potts (2013); Rigby and Cárceles (2001).
\item It needs to be noted that these numbers are difficult to measure since research cannot always be contributed to one or the other farming method. De Ponti, Rijk, and Van Ittersum (2012); Beintema et al. (2012); Tittonell (2014).
\item Willer and Lernoud (2017); Niggli, Willer, and Baker (2016).
\item Jacobsen et al. (2013); Scientific American (2009); Tittonell (2014).
\item Watson, Walker, and Stockdale (2008).
\item Kochupillai (2019).
\item As discussed in the introduction, today, 75\% of the world’s food is generated from only 12 plants and 5 animal species, world nutrition is primarily based on a mere 10 crops, of which three, namely, rice, maize and wheat, contribute nearly 60\% of the calories and proteins obtained by humans from plants. FAO (1999).
\item Ibid.
\item Sumner, Mair, and Nelson (2010); Wiskerke (2009); Pfeiffer and Vocks (2008).
\item Schoon and Te Grotenhuis (2000); Renting and Van Der Ploeg (2001); Batie (1989).
\item Kochupillai (2019).
\item Ratnadass et al. (2012).
\item Niggli, Willer, and Baker (2016).
\item Tittonell (2014).
\item Niggli (2013).
\end{itemize}
agroecology has not yet been developed, and discordant viewpoints prevented, until recently260, the further application and usage of the approach, for example, at a governmental level.261 Politics, institutional activities and innovation mostly focus on research priorities. Accordingly, agroecology is currently barely integrated in political activities e.g. in subsidy schemes.262 In addition, a gap in research funding results in sub-optimal crop and livestock breeding, which are of central relevance for organic (traditional) farming.263

The imbalanced research funds reveal a correlation between inputs and the amount of conducted research creating a focus on short-term input efficiencies in the current system. Consequently, it is mostly conventional, output oriented research that is funded, which creates a technical regime264 that locks out agroecological and traditional farming methods - especially since they have been shown to reduce input dependency.265 The current investments in big data analytics also currently focus on such input and capital intensive (technically complex) regimes and associated studies mostly focus on conventional farming.266 As discussed in the following sub-section, the goals of data analytics and the direction of data and information flows also need to be diversified, allowing the benefits of these systems to flow also to other farming systems. This diversification of research goals, as well as of directions of data flows, are necessary to re-balance the landscape of incentives for innovation, recognizing and also rewarding small farmers as integral and actively contributing members of an ‘innovation society’.267

Other researchers have emphasized that future research requires long-term commitment of funds that supports complex agroecological research involving many different ecosystem interactions268 on the one hand, and on groundbreaking,269 outside-the-box ideas, beyond classical linear approaches to research-supported innovations, on the other.270 For this, multi-disciplinary, multi-stakeholder research is not only relevant, but crucial and unavoidable. There is currently very little multi-stakeholder and multi-disciplinary research ongoing (e.g. research engaging not just scientists, but also social scientists, governments, extension services, farmers etc.), especially in the sphere of agriculture in India. This must be seen very critically,271 and immediate steps need to be taken, especially in countries like India that not only host major biodiversity hotspots, but also are home a vast and almost lost wealth of TEK based farming systems and associated know-how.

The question that arises, of course, is a practical one: Availability of research funding is limited. Further, given the dominating interests of stakeholders engaged with various aspects of conventional farming, how can re-distribution of research funds become a practical reality. Here again, as discussed above (Prong 3), smart use of emerging technologies such as blockchain/DLT and Artificial Intelligence (AI) based applications can help generate new research funds, making sustainable seed/agricultural research and innovations also self-sustaining vis-à-vis research funding. More details in this regard are provided in the next sub-section and in Annex 3.

B Big Data, Blockchain and Artificial Intelligence: Diversifying Directions of Data/Knowledge Flows to Equitably Monetize & (Re)distribute Value from Traditional Ecological Knowledge (TEK) Based Farming Systems

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260 More recently, India has declared its interest in wide spread adoption of ZBNF, which is considered a movement in agroecology. India Today (2019); Saldanha (2019); Ministry of Agriculture & Farmers Welfare (2019).
261 Sanderson Bellamy and Ioris (2017).
262 Wezel et al. (2018).
263 Münster (2017). As a result, organic farmers are forced to use conventional seed varieties with wide-reaching impacts on yields and plant health since these seeds are not suited for organic/traditional cultivation. De Ponti, Rijk, and Van Ittersum (2012); Ponisio et al. (2015); van Bueren et al. (2011); Döring et al. (2012).
264 Vanloqueren and Baret (2009).
265 DeLonge, Miles, and Carlisle (2016).
266 Wollert et al. (2017); Bronson and Knezevic (2016).
268 Vanloqueren and Baret (2009).
269 Tittonell (2014).
270 Hamm et al. (2017).
Across the globe, systems of varying degrees of complexity and sophistication, including, most recently, systems deploying blockchain, Artificial Intelligence (AI) and the Internet of Things (IoT) devices, have been developed that feed information to farmers with the aim of teaching them how exactly farming must be done to obtain a specific desired end result. Large agro-seed corporations are engaged in this effort; teaching farmers how exactly to use their “improved” seeds, fertilizers and pesticides to cultivate specific grains (notably corn and soy) using blockchain and AI,272 or using simple agri-input distribution and contract farming models to teach farmers which seeds and inputs to use to get the exact type of potatoes needed to make specific end products.273 Under broad umbrella terms such as ‘precision farming,’274 ‘contract farming,’ and ‘commercial farming,’275 the direction of information flow is, in all instances, from external (large, formal sector) sources to farmers (small, informal sector).276

Leaving the case of large corporations aside, since the Green Revolution, the structure and direction of information flow in the Indian agricultural sector has (also) primarily been as follows: – from the large, formal sector, comprising of governmental or private seed multiplication and distribution networks, to the small, informal sector, comprising of marginal, small, medium and also so called ‘large’ farms.277 Yet, as is clearly visible from the farmer stories compiled by Kopytko as well as from the plant variety protection data of the Plant Authority of India, farmers in India are scientists, researchers and innovators in their own right. More fascinating is the fact that these innovative farmers are often not keen on obtaining exclusive rights over their creations. Instead, they are eager to disseminate their ideas and knowledge (which ranges from methods of cultivation, types of seeds that are best suited for specific biotic and abiotic conditions, methods of seed storage and soil health maintenance) to other farmers (and to government research centers) to improve the socio-economic conditions of all farmers, to safeguard agrobiodiversity, the environment and soil heath, and to support the growth of the nation as a whole280 (see also Jitul’s story, Box 2 above).

In order to support the economic growth and well-being of such farmers, it is necessary to create marketplaces for their data, know-how and information. These marketplaces must facilitate transparent and profitable data/know-how sharing, ensuring, as far as is practical and equitable, that farmers/farmer communities can share their data and knowledge on the terms, and for a duration and purpose of their (collective) choosing.

In this context, it is noteworthy that although the direction of information flows has primarily been as described above, it is undoubtedly also the case that acquisitions of PGRs and ‘samples’ of agrobiodiversity, have been made (and continue to be made) by research centers and private entities (within and outside India) from farmers. As discussed above (Prong 3), these acquisitions are often made without giving any meaningful monetary or other benefit/recognition to communities that have provided this material and information.281 Now, significant PGR collections are in ex situ seed banks and are considered to be in the public domain, giving no incentive to the farmer-providers of the PGRs to continue cultivating and improving these in situ. While pockets of efforts are seen in government initiatives to recognize plant genome savior communities under the PPV&FR Act, the system leaves several farmers and farmers’ communities who have not been recognized (so far), feeling disillusioned or unhappy.282 Moreover, the one-time recognition does not provide farmers with the opportunity to share their innovations (in return for continuing economic benefits – e.g. through royalty payment) or to further develop means of benefiting from their innovations.

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275 Pingali (1997); Holloway (2002); Appleby (1902).
276 Sorensen et al. (2010); Fountas et al. (2006); Isaac et al. (2007).
277 Compare size of India’s concept of ‘large’ farm holding with the global or European average farm holding size. Kochupillai (2016).
278 Kopytko.
279 Kochupillai (2016); Kochupillai (2019).
281 Narloch, Drucker, and Pascual (2011); Halewood et al. (2018); Brush (2007).
282 Kopytko (2019).
In order to make agrobiodiversity/PGR conservation and its in situ improvement a more widespread practice (for social, environmental and economic reasons), i.e. to make it more of a norm rather than a rare exception, we need to find answers to the following two questions. These questions also arise from the farmers’ stories (See Box 1-3) and are mirrored in the challenges, issues and recommendations made by the participants of SSI 1.0:

1. How can the direction of information flows be changed – i.e. from the current “formal to informal”, to a “informal to informal”, and perhaps also “informal to formal”? 
2. More importantly, how can this shift in information flows be best managed in order to ensure that farmers transferring this information also obtain monetary benefits for each transfer, as well as a percentage of profits (micro-royalties) resulting from any downstream innovations and sales resulting from the original transfer of information?

It is envisaged that blockchain and AI based applications can help accomplish both of the above goals. However, and as a first step to building the envisaged solution, it is necessary to determine what types of data/information/knowledge can flow from informal to formal sectors, and to what uses can this information/knowledge potentially be put. While these questions can be the subject matter of a doctoral thesis, in line with the latest scientific findings linked with sustainable agriculture, (including concepts such as ecosystem services, soil microbial diversity, soil-root microbe interactions, etc.) the very basic categories of information/knowledge that can and should ideally flow from informal to other sectors (in return for equitable payment and sharing of benefits) can include information/knowledge on the following:

1. Methods of low cost, high value, organic, natural or traditional (zero chemical, sustainable) farming that are ideally suited to specific local conditions and local biotic and abiotic stresses;
2. Methods of seed storage that do not require the utilization of expensive equipment (such as very low temperature refrigerators) and can be utilized locally, including in remote regions;
   a. This could include knowledge about local herbs, weeds, cattle waste and other agricultural waste, and methods of processing these to create organic or ecofriendly seed stimulants or seed germination enhancers.
3. Methods and procedures of optimizing soil microbial diversity to enhance soil health and nutrient absorption by plants, thereby supporting higher yields from use of heterogeneous seeds and planting materials; 
   a. This could include knowledge about local herbs, weeds, cattle waste and other agricultural waste and methods of processing these to create organic or ecofriendly plant biostimulants, Compost Teas and other organic fertilizers with beneficial live microbial populations.
4. Knowledge about locally best suited indigenous/heterogeneous seeds and planting materials for a large diversity of crops, fruits, vegetables and/or cash crops, including methods of cultivating them for best results;
5. Knowledge about locally prevalent diseases and how to protect locally growing crops from these diseases without the need to use chemical pesticides.

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283 Erhard and Füssel (2016); Trap et al. (2016).
284 Suman, Yadav, and Verma (2016); Hartmann et al. (2015); Brussaard, De Ruiter, and Brown (2007).
285 Van Der Heijden et al. (2016); Lareen, Burton, and Schäfer (2016).
286 “For that reason, operators should be allowed to market plant reproductive material of organic heterogeneous material without having to comply with the requirements for registration and without having to comply with the certification categories of pre-basic, basic and certified material, see European Parliament and the Council (2018); Schmidt (2019).
287 Any substance or microorganism that is applied to plants to enhance the efficiency of nutrient uptake by plants. Such plant bio-stimulants include preparations composed of organic matter, and microorganisms and foster the fertility of the soil-microbiome and consequently, the plant growth and development is improved. Bundesamt für Verbraucherschutz und Lebensmittelsicherheit (2009); European Biostimulant Industry Council (2019).
288 Fermented tea extracts of composted materials which are applied to prevent and counteract plant disease. Especially the usage of either vermi-compost or thermophilic compost as a foundation advances plant growth. Koné et al. (2010); Pant et al. (2012); Scheuerell and Mahaffee (2004).
a. This could include knowledge about local herbs, weeds, cattle waste and other agricultural waste and methods of processing these to create organic or ecofriendly pest repellants and plant protection agents.

This information can be shared (in return for micro-royalty payments) via blockchain/AI backed platforms/marketplaces, with a wide range of end users, including farmers, scientists, industrial researchers etc. Each end user can be charged a different initial ‘bulk payment’ as well as differential rates of ‘royalties’ for fixed durations of time. The bulk payment and royalty amounts, as well as the duration for which royalties have to be paid must be determined by multi-stakeholder consultations and must be backed by appropriate amendments in the Biodiversity Act and the PPV&FR Act.

The commercial potential of this and similar information/know-how and collected data can be better gauged once the significant and growing interest in the same is recognized. For example, this information is of growing relevance for the creation of a wide variety of (industrial) products that are increasingly used in organic farming in the developed world, including, Organic Plant Biostimulants, Compost Teas, Organic Plant Protection Agents and several other products and processes (see also discussion under Section III above, vis-à-vis commercial relevance of soil microbial diversity emerging from farms engaged in TEK based farming.)

The vast market for the above categories of data can perhaps be glimpsed by this industry observation:

“Product developments in biostimulants involve observing plants and their ecosystems. Rigorous research is required to discover new bioactive compounds, identify beneficial microorganisms, and understand how synergies provide stronger effects than any single substance or microorganism working alone. It takes around two to five years to introduce a new biostimulant product to the market, since its initial conception. There have been several developments in the biostimulants product research over the last 20 years, which is now shifting toward advanced product developments. Further, monitoring crops to decide the time and way of application during product development is a challenge. In addition, the lack of knowledge and understanding on biostimulant usage, along with regulatory constraints in most parts of the world, poses additional challenges to study, in this domain.”

Accordingly, if India can re-direct its research efforts towards TEK based farming systems and their impact of seeds and soil diversity (as well as interactions between beneficial plant root bacteria and soil bacteria), they can, together with inputs from farmers engaged in such farming, discover new bioactive compounds, identify beneficial microorganisms, and understand how these compounds and microbial populations impact crop productivity. When this data and information is shared using blockchain/DLT and AI based apps, its usage can be tracked and charged, bringing in fresh research funds as well as concrete monetary benefits to farmers. Further, these technological solutions can help track, trace and obtain a share for Indian farmers and researchers, of benefits accruing from intellectual property protection resulting from the identification and conversion of these compounds and microbial populations into industrial scale products.

A preliminary theoretical outline of how diversified (farmer to researcher) data flows can be linked with Blockchain and AI-based apps that support widespread sharing and use of relevant farmer information, while also ensuring monetary benefits for those sharing know-how and research findings, is provided Annex 3. Further multi-disciplinary and multi-stakeholder research is necessary to build this outline up into a workable solution.

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289 du Jardin (2015); Khan et al. (2009); Ertani et al. (2015); Sharma et al. (2014).
290 Scheuerell and Mahaffee (2004); Manandhar and Yami (2008).
292 Mordor Intelligence, (2019).
V Conclusions

India has long supported and embraced innovations (e.g. Green Revolution, Bt technology) emerging from other countries, thereby contributing significantly to the economic development of these countries. Undoubtedly, Indian farming has also gained significant benefit from embracing these technologies, albeit at heavy cost. According to reports, for example, in 2018, India imported 42.03 lakh tonnes of urea for over USD 1 billion (for USD 1,048.59 million till November of this fiscal year). During full 2017-18 fiscal year, imports stood at 59.75 lakh tonne at a value of USD 1,295.72 million. India also imported 52.2 lakh tonne of diammonium phosphate (DAP), 4.04 lakh tonnes of nitrogen-phosphorus-potassium (NPK) and 27.53 lakh tonne of muriate of potash (MOP) till November of this fiscal. In entire 2017-18 financial year, India imported 42.17 lakh tonne of DAP, 4.99 lakh tonnes of NPK and 47.36 lakh tonne of MOP.293 Added to this are the costs of acquiring “improved” seeds: The costs for five years have been estimated to add up to around Rs 400 crore in Andhra Pradesh and Rs 584 crore in Rajasthan alone.294

Therefore, India needs to urgently re-think and diversify its agricultural priorities and associated laws and policies, especially if it wants to accomplish the three goals stated at the start of this paper:

(i) Goal 1: Expanding the role and contribution of small farmers in the Indian economy by helping them become “know-how providers and innovators,” rather than remaining mere “technology/innovation users.”

(ii) Goal 2: Expanding the choices available to Indian farmers vis-à-vis systems and approaches to agriculture, in order to facilitate a shift towards more sustainable (eco-friendly) agriculture, keeping the interests of all stakeholders, as well as the need to ensure long term food and nutritional security, in mind.

(iii) Goal 3: Expanding and strengthening India’s organic and circular economy and making India a world leader in the supply of organic seed and food.

It is worth recalling that almost 80% of India’s farmers are small and marginal farmers, a large % of which are currently engaged in subsistence farming, contributing little to their own, their communities’, or country’s economic growth. By adopting the three prongs, simultaneously or sequentially (depending on the needs, strengths and weaknesses of each region where the prongs are deployed), the very significant human resource of small farmers can become innovators and technology makers contributing in a diversity of different ways, to rural as well as national economies, while also supporting their own socio-economic growth. As a first step in this direction, it is necessary to impart education to farmers, agricultural extension officers and university students on TEK-based farming systems and curriculums that go well beyond the current focus on Mendelian genetics, F1 Hybrids and HYVs. Thereafter, the region-specific innovations and know-how emerging from the practice of TEK-based sustainable farming should be shared with other farmers, scientists and all stakeholders, albeit with mechanisms in place that ensure (a) clear traceability of source and downstream uses, and (b) equitable compensation and royalty payments to each value creator and value-adder.

At the same time, a rebalancing of incentive structures established by current laws and policies is necessary. As discussed in Section II Prong 3 and Section III, the incentives landscape is currently imbalanced and promotes ‘conventional’ farming over and above any/all other forms and approaches to farming. This legal and policy preference for conventional farming and associated (chemical/external) inputs, acts as a ‘perverse incentive’ that prevents the widespread adoption of farming systems that protect, use and recycle local resources, including local (desi) seeds and locally generated organic waste. More importantly, this preference prevents the evolution of robust local

markets for indigenous, heterogeneous seeds and associated know-how, to the socio-economic detriment of small farmers as well as their communities and the country as a whole.

By adopting the three-pronged approach, the Indian government can ensure that a new generation of TEK farmers can be created who, without uprooting conventional or other dominating farming systems, will boost the organic and circular economy of India, engaging small farmers as active contributors to this economy. As discussed above, a market for ‘uniform’, non-variable varieties can continue to exist. What is necessary in parallel, however, is to actively incentivize the evolution of a robust global, digital marketplace for high-quality, heterogenous ‘India Organic’ desi seeds and associated know-how, originating from the Indian grassroots. This is possible via clear, targeted and optimally regulated DLT/Blockchain solutions together with AI apps connected therewith. Supported by digital traceability, distributed (rather than centralized) certification/verification systems, and smart-contract based micro-payments and biodiversity token/points awards, the resulting digital market for heterogeneous materials would be especially useful for promoting organic or traditional agriculture within India and globally, bringing environmental as well as economic gains to small farmers and the Indian economy. Various ‘nodes’ within the DLT/Blockchain architecture could then also support decentralized quality control through reward-points based research that can, inter alia, check and verify the fact of heterogeneity and variability, together with the specific benefits and characteristics that the cultivation of each desi seed using associated know-how can bring to farmers in various cultivation environments.

The emergence of healthy and diversified markets for heterogeneous/indigenous seeds and associated TEK-based know-how, managed by small farmers with the help of various ‘nodes’ in the DLT/Blockchain solution, would encourage small farmers and farmer communities to become entrepreneurs. These entrepreneurs would then support the overall growth of the Indian agricultural economy by making India a world leader in providing indigenous, heterogeneous seeds, together with know-how for conducting sustainable ‘high value’ agriculture, adaptable to very diverse farm conditions, to farmers, researchers and corporations, all over the world.

With India’s dual strength in Traditional Knowledge and Information Technology, the development of solutions that help India better manage and monetize its vast agrobiodiversity and associated soil-microbial and plant genetic wealth should be neither expensive nor time consuming. While multidisciplinary research and multi-stakeholder inputs are necessary to build a nation-wide system, the best time to make clear and concerted efforts in this direction is now.
How can government policy in India – in particular, around intellectual property (IP) rights – incentivize innovation with indigenous varieties of seeds and other propagating materials? That was the question investigated in 2017 by a 9-month UK Arts and Humanities Research Council (AHRC) Global Challenges Research Fund (GCRF) project led by Principal Investigator Gregory Radick and Co-Investigator Mrinalini Kochupillai, in collaboration with the Art of Living (AoL) Foundation – a Bangalore-based worldwide charity with a strong commitment to promoting sustainable development – and Post-Doctoral Research Associate (PDRA) Natalie Kopytko (The Sustainable Seed Innovations 1.0 Project – SSI 1.0).

More specifically, SSI 1.0 was concerned with findings means of incentivizing farmer-level innovations on and with seeds from often-neglected indigenous varieties in India. It was also concerned, in particular, with the greater role that public recognition for (small) farmers’ seed innovation might play in that incentivization. This line of inquiry emerged at the meeting point of two research programs: first, Kochupillai’s study of how conventional IP together with trends in formal seed related innovations, and certain rural policies and practices are resulting in the gradual erosion of traditional culture of seed saving and exchange on which farmer-level innovation with indigenous seeds depends, and, from a broader perspective, on which in situ agrobiodiversity conservation depends; second, Radick’s study of how innovation in the technosciences generally involves interactions between patent claims – intellectual property narrowly construed (IP-Narrow) – but also two forms of intellectual property more broadly construed: priority claims (claims to have discovered or invented something first); and productivity claims (claims for the practical usefulness of a particular body of knowledge).

The SSI 1.0 project concluded with a unique multi-stakeholder conference and roundtable organized by the Art of Living Foundation (AoLF) at its headquarters in Bangalore in September 2017. 36 experts, representing academia, lawyers, NGOs, government and farmer groups from various parts of India participated in the roundtable, highlighted current challenges, and contributed concrete recommendations on means of promoting sustainable seed innovations, including amendments and additions to systems, structures and research focuses that can support this important cause. In particular, the multi-stakeholder conference and roundtable, together with the research based on qualitative data gathered through farmer stories, generated a set of new proposals for maximizing public credit for individuals (farmers, especially small farmers) and farmer groups who innovate with indigenous seeds.

The questions discussed by the project and the multi-stakeholder conference were important ones because, unlike the environmentally and socially damaging varieties imported during the ‘Green Revolution,’ indigenous varieties have been adapted for growth in local soils, climates, and human skill sets. As such, their promotion also has the potential to give struggling farming communities a distinctive commercial niche and a renewed sense of dignity – this is also clearly seen from the farmer

295 Kochupillai (2019a); Kochupillai (2016).
296 MacLeod and Radick (2013).
297 Participants: Sanjay Khattal (National State Seed Corporation and representative of the Government of India - GoI), Sunita Sreedharan (Advocate), Dr. Sunan Sahai (Gene Campaign), Dr. Kishore Kumar Sharma (Assam Agricultural University), Sanjay Patil (BAIF), C.S. Triphany (Art of Living Foundation), Umendra Dutt (Kheti Virasat Mission), Pitambar Shrestha (Li-BIRD), Ruchi Jain, Ankush Bhaelekar, Sanjay Maruti Patil, Shamika Mone, Udayakumar Kollimath, Kishore Mukherjee, Amarjit Sharma, Gulab Singh, Pankaj Pathak, Raspinder Singh, Santosh Kumari, Umendra Dutt, Yash Mishra, Arun T., Ajit Paul, Chanchal Biswas, Mahadev Ramkshina Gomare, Dinesh Gurjar, Jay Prakash Singh, Ranjit Kumar Singh, C.P. Krishna, K.C. Krishna, S.B. Somshek, Dandiram Dinker Madane, Satish Punja Kanawade, R. Sriram, Perumal R.
298 Chanti (2017); Jain (2010); Evenson and Gollin (2003); Pingali (2012); Conway and Barbier (2013); Smith, Elliott, and Bragdon (2015).
299 Girard and Frison (2018); Westengen and Brysting (2014); McGuire and Sperling (2016).
stories and interviews that were part of the project. Acknowledging the relevance, Mr. Sanjay Khattal, representative from the GoI at the conference, recommended the compilation of a position paper detailing concrete recommendations and action points for the government.

The results of Kopytko’s interviews with farmers, along with the testimonials and inputs of participants at the roundtable held at the AoLF campus in September 2017, were encouraging, and the Research Team, planned, as per the recommendations that came up during SSI 1.0, to develop this research into a position paper to bring before the Indian government. At the time, there was no notion that such a credit-tracking/publicizing system might be monetized. At that time, monetization of innovation was still being thought as strictly to do with successful marketing, especially marketing supported by patents and other forms of “IP-narrow”. There was also no link to the productivity-claims part of Radick’s “IP-broad” proposal, aside from the suspicion that exaggerated claims for the productivity of genetics, as the indispensable key to successful plant breeding, were part of the explanation for why the seed-saving-and-exchange culture needed support for its continuation in the first place.

B Sustainable Seed Innovations 2.0 Project

Since SSI 1.0, new work by members of the Research Team, done keeping the specific recommendations of the SSI 1.0 Conference/Working Groups in mind, has led to breakthroughs on both of these fronts. From Kochupillai has come an exciting vision for how blockchain technology can potentially be used to:

(i) better ensure profits from the sale of indigenous and heterogeneous seeds among and between farmers goes to each level of (small) farmer-innovators and farmers’ communities that first introduce that seed into the (blockchain) market,

(ii) support a differentiated pricing mechanism depending on the category of end use to which any buyer intends to put the farmers’ indigenous/heterogeneous seed to, ensuring that farmers receive higher prices from research and corporate buyers than from farmer and end consumer buyers incentivize; and

(iii) create a system where that various categories of end users that adds value to the system by, for example, conducting research on or with farmers’ indigenous seeds, or sharing additional (improved) materials and information gets points/tokens (similar to carbon points or cryptotokens) that can be exchanged and used for further research or other purpose.

The differentiated pricing system under the blockchain solution could help ensure that monetary benefits accrue in a manner that supports, rather than undermines, the culture of seed saving and exchange. In addition, the envisaged blockchain/DLT system could facilitate greater practical feasibility and ease of use to systems established under international instruments such as the International Treaty on Plant Genetic Resources for Food and Agriculture (the “Seed Treaty”) and the Convention on Biological Diversity (CBD), as well as their Indian counterpart, namely the Convention on Biological Diversity (CBD). These instruments support a kind of “productivity claim” by mandating “benefit sharing” with local and indigenous communities that grant access to Plant Genetic Resources (PGRs) that are used in breeding programs when the end result is protected by intellectual property. While the number of patents and plant breeders’ rights certificates issued for new varieties of seeds has been increasing rapidly within India and globally, there are little, if any, well known instances of benefit sharing with farmer communities that were the original custodians of these PGRs.

To illustrate the relevance of the three-pronged approach, the research team relies on stories of innovative farmers and farmer communities from various parts of India, compiled by Kopytko.

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300 University of Leeds (2019).
301 The Research Team for this position paper and the Sustainable Seed Innovations 2.0 project: Mrinalini Kochupillai, Julia Köninger, Natalie Kopytko, Jasper Matthiessen, Gregory Radick and Prabhakar Rao.
302 Lesser (2000); Borowiak (2004); Rosendal (2006).
303 Tsioumani (2018); Bjørnstad (2016); Oguamanam (2006).
Particularly interesting, is a brilliant example that has come from Prabhakar Rao (Art of Living’s) work with traditional and farmers’ varieties that have their own deeply impressive productivity claims to make (“inherent productivity”): the old/new “Wonder Wheat,” recently christened 
*Sona Moti* by Sri Sri Ravi Shankar (founder, Art of Living) – a 2,000-year-old Indian Emmer wheat, which preliminary lab tests have shown to contain three times more folic acid than any existing variety. Also coming from the NGO partners Art of Living, as well as other NGO and farmer participants of SSI 1.0 are valuable practical insights of Traditional Ecological Knowledge (TEK) based farming systems that support the inherent productivity of traditional/indigenous seeds. Indeed, several of the SSI 1.0 conference participants (particularly the farmer groups) shared similar experiences. Within specific indigenous cultural contexts where this inherent productivity enhances the self-respect and worth of the entire community that has helped preserve/resurrect the variety or engaged with TEK based farming systems that facilitate this, the relevance of productivity claims going beyond intellectual property protection regimes (“IP Narrow”) is further enhanced and finds concrete expression.

In line with the empirical experience of farmers and NGOs engaged in farming based on TEK, from Radick also comes a new way of teaching basic genetics which, by highlighting the importance of genetic backgrounds and gene-environment interactions as the main story (rather than an exception to the Mendelian rules), can help farmers understand why indigenous seeds grown in their home regions using traditional methods can be so much more productive as well as ecologically sustainable than the alternatives.304 The position paper recommends the incorporation of such a curriculum into existing agricultural curriculums of India to support diversification of the content of Indian agricultural education and extension services, spurring more research into TEK based farming systems as well as indigenous heterogeneous seeds that give best results in combination with such farming systems.

Based on the above work following the SSI 1.0 project and conference, the present position paper for the GoI has been compiled with additional funding awarded by the UK Global Challenges Research Fund (GCRF) to accelerate the impact of the 2017 research and conference findings. The aim of this impact-acceleration project is to help translate the proposals made in the 2017 conference into action, through:

1. the writing and publicizing of this research-based position paper for the Government of India, co-authored by the Research Team, with supporting comments and contributions from all signatories who participated in the SSI 1.0 and SSI 2.0 conference;

2. the web-based dissemination of the stories of innovative farmers, *inter alia*, through a dedicated website to be hosted by the University of Leeds and parallel stories linked and published through Art of Living’s websites; and

3. the outlining of novel Artificial Intelligence (AI) and blockchain/Digital Ledger Technology (DLT) facilitated frameworks to

   i. trace the source of seeds transferred from a farmer/farmer group to any other farmer/farmer group, researchers or other end users and ensure payment of ‘micro-royalties’ to the originators, improvers and value adders (‘miners’) throughout the PGR transfer chain; and

   ii. incentivize and generate funds for research and in situ innovation on and with PGRs contained in this agrobiodiversity with the aim of increasing the volume of research and bringing greater information about the characteristics and benefits of traditional and diverse seeds and planting materials (as well as of farming techniques associated with their cultivation and of the end products resulting therefrom), to farmers, end consumers and researchers, thereby increasing their value/demand.

304 Charnley and Radick (2013); MacLeod and Radick (2013).
An example framework for the above is provided in Annex 3 hereunder. This is a very basic and preliminary framework. Further multi-disciplinary research and multi-stakeholder consultations need to be done on this framework to develop sustainable and equitable blockchain/AI solutions that incentivize research and in situ innovation with agrobiodiversity, leading to socio-economically and environmentally beneficial sustainable seed innovations by all stakeholders, particularly small farmers.
Annex 2

Summary of SSI 1.0 Project Conference and Workshop Recommendations,
15th September 2017

The University of Leeds, the Office for Sustainable Development of The Art of Living Foundation and the Max-Planck Institute for Innovation and Competition initiated the Sustainable Indigenous Seed Innovation project in 2017, with funding from the Arts and Humanities Research Council, UK. The first phase of the project aimed to answer the research question, how government policy in India – in particular, around intellectual property (IP) rights – can incentivize innovation with indigenous varieties of seeds and other propagating materials. Consequently, the research goals of the first phase were:

- Examining incentives for farmer-level seed innovations from indigenous varieties in India.
- Investigating the role of public recognition for farmers’ seed innovation in creating incentives.

Following extensive qualitative research undertaken by the post-doctoral research associate, Dr. Natalie Kopytko during the first 9 months of the research grant period, the project culminated in a roundtable with various stakeholders to understand the challenges and needs of small and marginal farmers engaged in conservation and improvement of indigenous seeds and planting materials, from the grassroots level (the “Sustainable Seed Innovations 1.0 Conference”, or “SSI 1.0 Conference”). Interdisciplinary workshops fostered a rich interaction and discussion among farmer groups, government representatives, academics, NGO’s and intellectual property specialists.

The keynote address by the founder of the Art of Living, Sri Sri Ravi Shankar, as well as introductory talks by Dr. Prabhakar Rao (Trustee, Sri Sri Institute of Agricultural Sciences and Technology) and Rugmani Prabhakar (Head of the Office for Sustainable Development, The Art of Living) emphasized the importance of protecting heirloom, indigenous and traditional seeds (called Desi Beej in India) that are more robust in marginal environments and have greater immunity against local diseases and climatic shifts.

Following the introductory session, detailed presentations were made in the plenary session by Dr. Natalie Kopytko (University of Leeds), Prof. Gregory Radick (University of Leeds), and Dr. Mrinalini Kochupillai (Max Planck Institute) on their individual academic research, including trends in seed saving among farmers and how existing intellectual property protection regimes and associated policies are ill equipped to promoting sustainable seed innovations among small and marginal farmers. The presentations also identified government policies that, in their effort to promote high yields over and above all else, end up disincentivizing agrobiodiversity conservation, soil and water conservation.

Presentations on diverse issues were also made by Ms. Sunita K. Sreedharan (Lawyer and Patent Agent), Sanjay Maruti Patil (BISLD), Pitambar Shrestha (LI-BIRD), Dr. Kishore Kumar Sharma (Assam Agricultural University), Dr. Suman Sahai (Gene Campaign), Shamika Mone (OFAI) and Sanjay Khattal (National Seeds Corporation). The areas they covered included challenges and loopholes in the biodiversity law of India, and various on the ground challenges faced by farmer groups in India, especially those engaged in protecting and improving indigenous/traditional seeds using traditional, sustainable agricultural methods. Farmer groups from various regions of India (Bengal, Jharkhand, Karnataka, Rajasthan, Tamil Nadu, Uttar Pradesh, and New Delhi), academics, lawyers, NGO’s and representatives of the Indian Government were present at the plenary session.

Due to the complex nature of the topic and the diversity of stakeholders involved, the challenge that the SSI 1.0 project & conference team needed to address was, how best to gather and integrate the different, but interconnected concerns and points of view. Indeed, the aim of the conference was not only to facilitate an interaction between experts from fields as diverse as biodiversity conservation, food security policy, ecological agricultural practices, seed policy and intellectual property law (as was done during the plenary sessions). The primary aim was to ensure that small farmer-entrepreneurs engaged in in situ

305 Kopytko (2019).
agrobiodiversity conservation via the cultivation of traditional/indigenous seeds using traditional farming practices, participate and contribute actively, voicing their own ground level concerns. To facilitate this, the second half of the one day workshop divided all participants into four groups:

(i) Policy, Legal frameworks & Intellectual Property
(ii) Participatory plant breeding,
(iii) Outreach and awareness of indigenous seeds
(iv) Importance of Research on sustainable seed innovation.

All groups identified current problems and collected recommendations for future actions to address/resolve these problems. A summary of the identified problems and recommendations emerging from each group is provided here in below:

The recommendations of the group “Policy, Legal Frameworks & Intellectual Property”, (moderator: Ms. Sunita K. Sreedharan, Lawyer and Patent Agent) were found to broadly fall under the following categories:

(i) **Inadequate attribution** and recognition given to innovative farmers and farmers’ communities, especially those engaged in saving and improving not just indigenous seeds, but also associated indigenous/traditional, sustainable and cost-effective methods of seed storage, soil health management etc.

(ii) **No traceability of source of seeds** and information. The farmers said that their improved varieties must be given names and these names must be recorded somewhere, together with basic characteristics of seeds (including history of where the seed came from, physical size, morphology, maturation period, diseases linked with its cultivation, or those that are avoided by their cultivation) such that anyone who buys them knows the source and attributes of the seeds. The names given to the seeds by farmers must be registered in the government seed portal or in any other centralized system. Farmer Producer Organisations (FPOs) must be created and FPOs must name the seeds emerging from any community of farmers. It was also recommended that in the absence of a tracing (to source) mechanism/system, farmer to farmer seed exchanges and exchanged seeds within farmers should be documented on blank papers with details as to time, date of sale/exchange, amount of seed given, sellers and buyers’ name etc. The farmers considered this to be necessary in order to claim royalties in the future (e.g. from those using/multiplying their seeds) and have an additional source of income.

(iii) **Documentation of Traditional Knowledge**: The group emphasized the relevance of documenting the traditional knowledge associated with every cultivated indigenous seeds (e.g. germination time, methods of cultivation for best results etc.)

(iv) **Inadequate availability of affordable, good quality indigenous seeds** for use in traditional, sustainable farming systems was identified as a major problem. The group concluded that more FPOs need to be formed in order to guarantee the availability of affordable, high quality indigenous seeds.

(v) **Lack of effective communication and marketing channels**: The group found that the help of the District Magistrate may be necessary in setting up mandatory marketing channels to distribute organic products of indigenous seeds, for e.g. by reserving spots for organic produce in various shops.

(vi) **Cost differential between organic and non-organic** and low shelf life of organic food in shops prevents indigenous seeds from becoming more popular.
Testing Labs to certify organic products needed in village level in order to ensure the quality and prevent the misuse of indigenous seeds and organic brands.

The group “Importance of Research on Sustainable Seed Innovation”, (moderator: Dr. Mrinalini Kochupillai, Max Planck Institute for Innovation & Competition), found that research is of central relevance to test, validate and increase the value, demand and interest in indigenous seeds and food resulting therefrom. Research is also needed to support and advance in situ (and ex situ) conservation efforts. Research is necessary not only to check/validate claims associated with indigenous seeds, but also to support nutritional security. For example, if a local variety of wheat is traditionally known to be rich in iron, research confirming this attribute would help bring knowledge about the benefits of the wheat to anemic people, helping them address their health problem, while also increasing the demand for the wheat and therefore, the farmers’ income. In addition to studying specific claims, broad based research also needs to systematically study the nutritional content (micronutrient content, quality, and yields of produce/grains resulting from the use of traditional/indigenous seeds and associated farming practices. All research efforts would help increase the value and demand of traditional seeds and food produced therefrom. In addition to these general research needs, the workshop participants identified the following areas in which research efforts need to be intensified to study:

A) Biological Research:
(i) Inherent pest resistance of traditional versus conventional seeds
(ii) Medicinal properties of local, indigenous grains
(iii) Impact of traditional ecological knowledge-based soil management systems on ecosystem services, plant health, yield, farmer profit margins etc.
(iv) Genetic studies on indigenous seeds, including study of active molecules and active ingredients in indigenous varieties, as well as interaction between these active molecules and ingredients in natural conditions;
(v) Impact of chemical / conventional farming on yield of traditional/indigenous seeds over time
(vi) Scientific guidelines for in situ seed conservation and improvement
(vii) Study on impact of traditional seed storage methods on seed viability

B) Mechanical Research
(i) Development of small and affordable machines such as processors, mixers, harvestors, water extraction machines, machines supporting traditional seed and grain storage methods, that can support the work of small farmers engaged in traditional knowledge based farming using indigenous seeds
(ii) Methods and machines to promote local processing of foods and other materials emerging from TEK based farming using Desi Seeds.
(iii) Low cost machines for bottling and vacuum packing at rural level

C) Comparative field research
(i) Research on field comparing yield from conventional farming using uniform/‘improved’ seeds versus traditional knowledge based agriculture using indigenous/heterogeneous seeds;
(ii) On field research to see if current cultivation practices associated with any traditional/indigenous seed are equally applicable in all conditions and situations and what changes are needed for specific local conditions to give best results;
(iii) Research and innovation in the finished product sector using unusual, unique produce and cereals cultivated using traditional/indigenous seeds;
Creation of recipe books using local, indigenous foods, which provide well researched details such as cooking time, storage tolerance, whether soaking, sprouting etc. is recommended and with what effect.

**D) Social Sciences Research**

(i) Determining means of making certification (safety related, organic certification etc.) more affordable and accessible to small farmers and farmer communities
(ii) Means of changing (negative) perceptions associated with traditional farming and indigenous/heterogeneous seeds
(iii) Developing efficient marketing models and compilation of best practices
(iv) Developing research methods that can appropriately incorporate farmers' observations into scientific research
(v) Historical and cultural research to study the linkages between specific crops and festivals or occasions such as weddings, child birth etc.
(vi) Historical research into farming systems and practices that existed before the green revolution (revival of ‘lost’ traditional knowledge)
(vii) Research on intellectual property rights and means of incentivizing in situ agrobiodiversity conservation and sustainable seed innovations such that economic benefits reach farmers and farmer communities without eroding local cultures such as cultures of seed sharing.

**E) Education**

(i) Re-thinking existing educational curriculums (e.g. in schools, universities, agricultural extension services etc.)
(ii) Education for value added product development linked with traditional seeds and produce/cereals resulting therefrom, including packaging, preservation etc.

The group “Outreach and Awareness of Indigenous Seeds”, moderated by Shamika Mone (OFAI), identified lack of incentives for engaging in traditional farming as well as lack of knowledge necessary to start the journey, as major problems. The group identified the need to support the creation of knowledge (associated with traditional farming) and its widespread distribution. Various recommendations were made to sensitize farmers and the general public about the importance of indigenous seeds (and traditional, sustainable farming systems). These included the introduction of new educational curriculums in schools, universities, activating and (re)orienting public distribution systems, and activating biodiversity committees to ensure not just the prevention of biopiracy, but to promote active on the ground, in situ agrobiodiversity conservation and improvement efforts. The findings of the group emphasized that community involvement would not only promote the revival of TEK, but could also foster development of local markets and employment opportunities through e.g. festivals with focus on local food and seeds. The group also recommended the involvement of celebrities and spiritual leaders to raise awareness and increase public involvement in traditional, sustainable farming using indigenous/heterogeneous seeds. The group recommended that in the short term, a starting point to create knowledge would be the documentation of success stories to spread motivation within farmers. Different types of media, such as films, web-portals, social media, magazines and books, could promote the effectiveness and reach of spread knowledge of indigenous seeds and their properties.

The group “Participatory Plant Breeding”, moderated by S.C. Thripati (Head of Agriculture Department, Art of Living Foundation), emphasized the importance of the traceability of indigenous germ plasms from farmers’ fields to varietal crop breeding programs. Ideas, that were proposed included support and funds for research, documentation of research and knowledge creation and further dissemination of seed material. In addition to these general proposals in the field of participatory plant breeding, the workshop participants recommended to focus efforts in the following areas:
(i) **Documenting the soil condition** to discover changes and derogations to counteract in time and prevent soil degradations (erosions, loss of fertility, etc.)

(ii) Maintaining a certain **distance between different breeds of crops**

(iii) **Testing the characteristics of seeds**, including Tagging (noticing the nutrient level in grains) whereby a standardization frame could provide help to document the results

(iv) Roughing the not so good quality of seeds

(v) **Signing of a Memory of Understanding** by the Government with the farmers so that the farmers can transfer seeds only under certain conditions

The roundtable event enhanced the understanding of the value creation in farmer innovation. The gathering of the different stakeholder revealed the requirement of a **documentation system** as the biggest challenge. Such a system was considered necessary to ensure **traceability to the origin of seeds**. Without traceability to source, a **reward/royalty system** cannot be established, and farmers cannot benefit from the multiplication and distribution of their seeds. Well documented knowledge creation and traceable channels of dissemination of knowledge would support knowledge creation and also the wider dissemination of seeds. A better documentation would counteract the erosion of TEK, especially if this knowledge is directly integrated in education. Education is a crucial recommendation prong that should foster public education and growers training, simultaneously (e.g. through extension services).

Further benefits, also on an economic perspective, could comprise **government schemes and subsidies for innovation**, distribution and the **in situ** conservation of indigenous seeds. The establishment of market structures for indigenous seeds could provide further monetary value that promotes farmer innovation and according products would contribute to a rising awareness of costumers.

The outcomes of the conferences were presented as recommendations to the Indian Government, based on which the suggestion that a position paper for the GoI be compiled, emerged.
Annex 3

A Non-technical, Preliminary Outline for a Blockchain Facilitated Solution to Incentivize, Monetize and Manage Research and In Situ Innovation with Agrobiodiversity for the Socio-economic Benefit of Small Farmers

Mrinalini Kochupillai

Feedback and comments welcomed from experts and stakeholders

Agrobiodiversity, particularly landraces and farmers’ varieties, hosts a wealth of plant genetic resources (PGRs) that contribute significantly to global food security and sustainable agriculture. While agrobiodiversity can be preserved ex situ, problems of viability over prolonged storage, and constantly changing biotic and abiotic conditions on field, make in situ agrobiodiversity conservation a necessity. However, farmer-custodians of agrobiodiversity have little incentive to continue cultivating landraces and farmers’ varieties, especially when faced with the option of cultivating formally “improved”, high yielding varieties. Farmer-custodians of PGRs are also unable to obtain a good price for their varieties, in part, because farmers’ varieties are inappropriate candidates for protection under existing intellectual property protection regimes. The culture of sharing prevalent among farmers, and inability to monitor the specific end use to which their varieties are going to be put (e.g. simple consumption or downstream research), further prevent monetization of PGRs. The fundamental problem here is in identifying who the first farmer (group) was that put a PGR on the “market”, who subsequently bought it, and what they did with it. Blockchain or DLT can help track this movement in an immutable way, and together with smart contract supported micropayments, can help monetize and manage this enormous, untapped genetic wealth. Using the Oxford Blockchain Strategy Framework, this Annex outlines a preliminary, non-technical blockchain use case for incentivizing research and in situ innovations with agrobiodiversity, for the benefit of small farmers and researchers.

Outlining a blockchain use case for research and in situ innovation with agrobiodiversity: The key considerations:

1. Blockchain use cases work on process that are repeated and can be automated. In the present case, farmers will continuously place their in situ improved/conserved seeds/varieties (containing PGRs) on the virtual market and various categories of buyers/stakeholders (see question 2) will continuously buy these. Also, there will be a repeated process of “improvement” of PGRs by downstream users, including researchers and businesses, necessitating repeated payment of micro-royalties. However, as seeds are not digital data, automation will require support from specific systems and machines that permit tracing of physical goods associated with transactional data entered on the blockchain.

2. Blockchain use cases are more appropriate when the transactions are ongoing (e.g. as a chain) rather than one time. In the present case depending on the nature of the “buyer”, the transactions can be one time or ongoing (in a chain). For example, a consumer may buy the seeds/varieties only for a one-time consumption. A researcher, on the other hand, will buy them

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308 Swanson and Goeschl (2000); Kochupillai (2016).
309 Kochupillai (2016).
310 The Oxford Blockchain Strategy Framework used to compile the initial version of this outline is a part of Oxford's Blockchain Strategy Program that was completed by Mrinalini Kochupillai in June 2018. The central/core part of this outline presented here was first submitted by the author as part of her final exam to Oxford (June 2018) and received the highest grades in the class. Additional research has been done by the author since then to develop the outline to its present state. However, further multi-disciplinary research and multi-stakeholder consultations will be necessary to check this framework and to make appropriate modifications as needed for India’s needs, before it is ready for rollout for the benefit of Indian small farmers. This Annex is offered to experts as a starting point for discussions.
to conduct further (downstream) research on the seeds and perhaps release an improved “new” variety that will be further sold to other farmers and researchers. On the farm, farmers will also keep improving the PGRs in situ, adapting them, in the process to local biotic and abiotic stresses. This will keep up the demand for their renewed PGRs on the blockchain facilitated marketplace.

3. To design an appropriate blockchain use case, it is necessary to know who the stakeholders are. In the present case, stakeholders are (i) the farmers, (ii) other farmers who may want to borrow or exchange seeds with such farmers, (iii) end consumers who buy these varieties for their nutritional value or other properties, (iv) NGOs; (v) scientists / research centers who would want to study the properties of the PGRs or use them for creating new/improved varieties, (vi) various government/regulatory bodies, including the Biodiversity Authority, the Plant Variety Authority, Public Sector agencies that check seed quality, organic certifying agencies, the State Seed Corporations, the government research centers etc.; and (vii) private sector, including the seed industries, plant breeders, private seed quality certification bodies, private organic certification bodies etc.

4. The regulatory framework that is currently regulating the subject manner (research and in situ innovation of agrobiodiversity) needs to be worked into the broader concept of the use case. Current regulatory structures are under the Indian Biodiversity Act, 2000 and the Protection of Plant Varieties and Farmers Rights Act, 2001. However, currently, there is no one central authority that is accumulating or storing such data (including transactional data and data tracing movement of PGRs) at all since there are no known means of doing so in a meaningful way. Only storage being done is of ex situ reserves in seed banks. This use case is specifically for agrobiodiversity conserved and improved in situ, and research done on this agrobiodiversity by various stakeholders including farmers themselves, researchers, plant breeders etc.

5. It is necessary to identify what the ‘value’ is that is transferred. In our use case, each stakeholder (see Pt. 2 above) places a different value on the PGRs contained in the seeds/varieties being sold by small farmers. Currently, due to lack of adequate information and infrastructure, farmers are unable to price discriminate and obtain the correct value for their PGRs and the transfer of value is therefore skewed.

6. In the light of a recent (new) conceptual understanding of blockchain\(^3\)\(^1\), it is also useful to see if there is a possibility to ‘add’ value with each layer of transaction. In the present case, each farmer or researcher that adds information about the characteristics or growing method is potentially adding value to the underlying PGRs.

7. In any blockchain use case, an immutable record must be mandatory. In the present case, as discussed in Prong 3, an immutable record is of paramount importance, especially when combined with smart contracts. This would ensure that any person who uses the PGRs for any purpose other than consumption/cultivation, pays a higher price and an automatic royalty (micro) payment mechanism gets triggered in case of sale of downstream “improved” seeds.

8. To develop any blockchain use case, it is useful to think about whether the blockchain will be public, private, permissioned, permissionless, and whether any specific features are necessary in the overall design. For the present purpose, it is envisaged that a private permissioned chain will be needed to begin with. This will ensure that those who join as contributors of value (i.e. the farmers who contribute PGRs for transactions managed by the blockchain) are authentic and contributing high quality PGRs. As the system gains recognition, it can move to a public permissioned blockchain and eventually, to an open public permissionless system. In each step, the programming and functionality (including end-user design) are key to the success of the initiative. It is also important that the number of transactions the platform can handle is high.

\(^3\)\(^1\) Kochupillai (2019a).
enough as we move from private-permissioned to public permissionless set up, without compromising immutability. For this, Etherium seems currently to be the best option, especially because it also permits weaving in of smart contracts.\textsuperscript{312} It is not necessary that the selected platform already has a large user base. It can (eventually) become a public semi-permissioned blockchain which is used only for PGR management and monetization. The above described use case may require complex programming/coding to ensure that the “value” inherent in each of the PGRs placed/traded on the DLT is adequately captured and benefit sharing takes place equitably throughout the transactional network. In fact, given the multiple sources of “value” that can potentially be contributed to this blockchain, it is possible that the forking of the blockchain is no more a “problem” but an asset to the larger goals sought to be accomplished by the blockchain.

9. The outline also considers who should run a node, why and with what kind of access rights (read, write, both). In the present system, all stakeholders (or stakeholder representatives, such as NGOs) can be nodes. They can also contribute as ‘miners’ actively adding “value” to this blockchain:
   a. Farmer-contributors of PGRs (or farmer cooperatives/NGOs working with farmer groups) – they will be the ones contributing PGRs of value that will be transacted and monetized using the blockchain. They will have read and write access. This is needed to ensure that they can keep track of where their PGRs are, add more or withdraw PGRs placed on offer, make claims for royalty shares that do not get automatically processed for some reason, etc.
   b. Farmers who want to share/exchange seeds with other farmers engaged in in situ agrobiodiversity conservation. Same as above – any farmer that is exchanging/“borrowing” seeds and cultivating them, is a potential contributor to the PGRs on offer via the blockchain.\textsuperscript{313}
   c. NGOs that farmers and farmers’ associations trust, can act as receiving nodes for the physical goods (seeds or other information e.g. cultivation mechanisms) as well as for recording the original transactions vis-à-vis the transfer of any PGRs.
   d. Universities or research centers who want to conduct research on or with PGRs conserved by farmers/farmer groups. In addition to playing the role of “nodes” that have read and write access, Universities and research centers can also play the role of “miners” that conduct research on the PGRs, for example, to scientifically validate the claims of the farmers vis-à-vis features peculiar to the PGR in question.
   e. Businesses that want to conduct research on or with PGRs, and/or want to multiply and resell the same. Same as c. above.
   f. Various public and private sector agencies can also act as nodes or miners that ‘check’ the authenticity of the data/information entered (e.g. whether the seeds have the quality they claim to have, whether the seeds are truly organic etc.) Government authorities such as the Biodiversity Authority can act as regulatory nodes that check whether the PGRs have been transferred under legally appropriate contractual terms and/or smart contract programs.
   g. End consumers who do not engage in research or testing on or with the PGRs, but merely consume the seed/plant variety, for example, as food, can have partial read access to check the provenance of their food. They do not need to have access to the entire log.

Because of the large and diverse set of potential nodes, miners and end users, the data storage requirements will be considerable as time elapses. Cloud based data storage can be considered to begin with. However, to secure the data, the Indian government can consider developing its own cloud infrastructure over time, space and programs on which can also be leased out to other use cases and users.

10. It is necessary to know who will be the users and beneficiaries of the envisaged system and whether any precautions need to be taken when rolling the system out. Any dapps that are

\textsuperscript{312} Cryptomorrow (2018).
\textsuperscript{313} Thomas et al. (2011).
created based on the above use case, will be used by all the “nodes”, the miners as well as by end consumers (i.e., by all stakeholders). It is mandatory that such dapps and the underlying mechanisms are covered by smart contracts as well as by laws that are currently in place to regulate this field. At present, the tendency of farmer-cultivators is to sell their entire produce to the government or to the highest bidder (usually a wholesaler or other intermediary) or to give away a sample of their produce for free to anyone who wants access to it. Now, instead of relying on the price fancies of a local buyer, the farmers can access global buyers and obtain differential prices from different categories of buyers/stakeholders. For this, some degree of behavioral and organization change will be necessary. In some rural areas, there might also be violent retaliation by powerful intermediaries who might lose their means of livelihood overnight! Skillful deployment of this platform will therefore be necessary, taking local governments as well as law enforcement agencies into confidence. Further, often times, farmer-conservers either don’t have any market at all for their seeds/varieties, or they themselves don’t know their value. They therefore either stop cultivating such varieties or they cultivate limited quantities for personal consumption. Once the demand and value of their efforts is recognized and economic rewards accrue, there will be much more of an incentive to continue conserving and improving PGRs in situ. As discussed in prong 2 above, education of farmers, scientists and RAEOs is centrally relevant to the success of the system.

11. What are necessary add on features of the envisaged blockchain use case. As discussed in Prong 3, the system should permit for not just automated payments, but also automated reward points being given. A cryptocurrency/token may or may not be necessary/beneficial – this needs to be investigated by experts. Further, it is necessary that the system automatically ensures a differentiated payment structure based on user categories. For example, users can be categorized as “end consumers”, “researchers”, “industry”, “NGOs” etc. While end consumers may only pay the market per KG rate, researchers and industry end users must be charged a much higher one-time payment, in line with the ‘value’ they place on the PGRs acquired. Also, as discussed in Prong 3 above, the award points must be tradeable for real cash from one or the other source, for example, either from the Gene fund, the biodiversity fund or a special/new biodiversity tax. This will ensure that stakeholders are encouraged (incentivized) to use the system rather than avoid it.

12. What are the legal and ethical issues to be considered. As outlined in Section III of the position paper, several legal and ethical issues need to be borne in mind when executing/rolling out the envisaged system. It must be rolled out step by step, perhaps one stakeholder at a time. The coding of smart contracts must be guided by well thought out ethics codes as well as by existing regulations.

13. As Blockchain is essentially a tool to manage data, applications other than dapps can also be built-up on blockchain architectures. In particular, Artificial Intelligence/Machine Learning apps can be built on the envisaged blockchain solution to support the monetization of any and all data, know-how and information contributed by farmers to the blockchain. This will permit the diversification of data flows (and therefore also diversification of monetary flows) for the benefit of small farmers. A simple system in this regard is outlined herein below:

Outlining a hypothetical flow of know-how/research data and monetary compensation therefor:

Imagine a farmer group or NGO or researcher named G, engaged in farming system F, contributes information about an organic/natural herb/crop C, that when processed using method M, and sprayed on organic farms, reduces the prevalence of Pest P. When G contributes this information through a blockchain using his/her/their private key, the AI (or blockchain) system can record this contribution of information and automatically implement the following steps (in the below sequence):

1. Give a time stamped confirmation to G, together with a hashed version of the information shared, so as to make an immutable record of the source and exact contents of the information or information-set shared
a. Note: The AI+Blockchain system created can recommend specific formats in which various nodes or contributors to nodes can share information;

b. larger information sets that involve interaction between several data components can be split into pockets of more precise data, with each pocket linked to the previous pocket in a logical, sequential manner akin to the steps to be followed in a recipe.

c. Each pocket of data and each set of interacting data pockets can be hashed sequentially and inter-relationally to form data protected with hashes in the form/structure similar to the structure of a Merkle tree.

2. A dormant token or ‘biodiversity’ award point with a specific fiat currency value must be issued to the contributor of data

   a. The dormant token value can be valued based on pre-decided categories/slabs of compensation;

   b. These compensation slabs must be organized based on specific categories of information, for example: Contributions that are organic, circular, low cost, easy to duplicate, use and be checked by small farmers must be given the highest value as it will have the highest immediate usability and positive impact on the environment; contributions that are non-sustainable, chemical or not so easy to replicate must be given lowest values as they will likely only be produced by a small group of people who would then capture most of the surpluses.

3. Invite ‘Miners’ or ‘researchers’ who have the resources necessary to test the claims of the contributor, to check the veracity of the data. Once the single pocket of data or the set of several inter-related pockets of data are received by the system and a time stamp + hash is sent to G, sharing of data with every invited miner who accepts the invitation, must be recorded by the system. Who can be invited to “mine” or “check” the data/information:

   a. Miners can include all farmer-researchers who want to test the suggestion on their own farms and give feedback;

   b. Miners can also be researchers in govt or private R&D labs;

   c. There should be a competition among miners as to who is the first (or who are the first ten) to check and confirm the veracity of the data or to reject the veracity either based on inadequate or statistically insignificant confirmation.

   d. Each confirmed veracity can lead to an increase in the value of the dormant token;

   e. Unconfirmed or rejected veracity will lead to the token remaining dormant and its value not increasing;

   f. Once a specific set of confirmations (10 or more) are received from various sources (farmers, researchers, consumers, as appropriate), the original token will stop being ‘dormant’ and will become ‘active’, which means it is ready for being traded in the market or being exchanged for cash from one of the sources identified in Prong 3 (or from any other source that is identified through expert consultations).

   g. This token will be purchasable at a specific minimum starting price (which will be at least 10 times the original value placed on the token at the time of being issued in dormant form to the data contributor);

   h. The token need not, however, be sold at the minimum starting price. It can also be sold to the highest bidder who expects the value of the token to increase over time based on the balance of evidence shared by the initial 10 confirmers of value + any number of rejectors/non-confirmations of value.

   i. Once the token/point becomes active, it can also be traded in the open market like a stock whose value can rise or fall based on demand and usage of the underlying data/information, or be traded like a carbon point (similar to emission trading).

   j. All uses of the confirmed information should be recorded on the blockchain and the effect of the usage must also be recorded on the blockchain – depending on the value added by the additional usage data contributed to the blockchain, additional
token/award points or fractions thereof can be issued to the contributors, who can, again, exchange the tokens/points for cash from the various suggested sources or by trading. The name of the token/point issued must remain constant, so it can help grow the value of the token.

4. After the lapse of a specific time (to be determined by stakeholder and through multidisciplinary research), the data must be made available for a high price to corporate and other players who can conduct further R&D&I activities on it to develop downstream products and processes. Bulk sums must be contributed, to be proportionately shared among all previous value contributors, and additional tokens to be issued to the corporate contributor based on predictions as to the value that can be added (and intellectual property rights obtained). In addition, once any downstream product is created and marketed, smart contract facilitated, automated micro-royalty payments can flow to originators and to specific categories of ‘miners’, e.g. miners who contributed most to the verification and testing of specific information/data contributed by any farmer. Fundamentally, the aim of the system should promote and incentivize research and in situ improvement of agrobiodiversity.
Bibliography:


Ahuja, Uma, SC Ahuja, and Rashmi Thakrar (2011). ‘Traditional Paddy Storage.’ *Asian Agri-History* 15, no. 3.


Ananda, C (2011). ‘Augmentation of Plant Growth Promoting Microorganisms through Fermentation of Cow Dung and Cow Urine.’ *University of Agricultural Sciences GKVK, Bangalore.*


Correa, Carlos María (2000). ‘ Options for the Implementation of Farmers’ Rights at the National Level.’


De Schutter, Olivier (2009). ‘Seed Policies and the Right to Food: Enhancing Agrobiodiversity and Encouraging Innovation.’ *Background document to the report (A/64/19) presented by Prof. Olivier de Schutter, Special Rapporteur on the right to food, at the 64th session of the UN General Assembly.*


Feher, Judit, Susanne Padel, Adanelia Rossi, Dora Drexler, and Bernadette Oehen (2010). ‘Diversified Food System: Policy to Embedding Crop Genetic Diversity in Food Value Chains.’


Hamm, Ulrich, Anna Maria Häring, Kurt-Jürgen Hülsbergen, Folkhard Isermeyer, Stefan Lange, Urs Niggli, Gerold Rahmann, and Susanne Horn (2017). 'Research Strategy of the German Agricultural Research Alliance (Dafa) for the Development of the Organic Farming and Food Sector in Germany.' 'Organic Agriculture' 10, no. 3: 225–42.


Ho, Melissa D (2010). 'International Treaty on Plant Genetic Resources for Food and Agriculture.' 'Plant Genetic Resources and Food Security' 10, no. 5: 528–53.


Plant Variety Authority India, The ‘Protection of Plant Varieties & Farmer’s Rights Authority India.’
http://plantauthority.gov.in.


https://www.scientificamerican.com/article/do-seed-companies-control-gm-crop-research/


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Sumner, Jennifer, Heather Mair, and Erin Nelson (2010). 'Putting the Culture Back into Agriculture: Civic Engagement, Community and the Celebration of Local Food.' International Journal of Agricultural Sustainability, 8, no. 1: 54–61.


Thomas, Mathieu, Julie C Dawson, Isabelle Goldringer, and Christophe Bonneuil (2011). 'Seed Exchanges, a Key to Analyze Crop Diversity Dynamics in Farmer-Led on-Farm Conservation.' Genetic Resources and Crop Evolution 58, no. 3: 321–38.


Thomason, Jane, Mira Ahmad, Pascale Bronder, Edward Hoyt, Steven Pockock, Juliet Bouloupe, Katrina Donaghy, et al. (2018). 'Blockchain—Powering and Empowering the Poor in Developing Countries.' In Transforming Climate Finance and Green Investment with Blockchains, 17–52. Elsevier.

Thompson, KA, E Bent, D Abalos, C Wagner—Riddle, and KD dunfield (2018). 'Soil Microbial Communities as Potential Regulators of In Situ N2O Fluxes in Annual and Perennial Cropping Systems.' Soil Biology and Biochemistry 113: 262–73.


Turpin, Grégoire (2016). 'Decentralization and Liberalization of Seeds and Plant Genetic Resources Regulations in Europe: A Danish Case Study.' Norwegian University of Life Sciences, Ås.


van Bueren, ET Lammerts, Stephen J Jones, L Tamm, Kevin M Murphy, James R Myers, C Leifert, and MM Messmer (2011). 'The Need to Breed Crop Varieties Suitable for Organic Farming, Using Wheat,


Walch, Angela (2019). 'In Code (Rs) We Trust: Software Developers as Fiduciaries in Public Blockchains. '


