



The Importance of Sustainable Seed Practices

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Abstract

The dynamism and diversity of seed practices is highly crucial to the health of the global food systems. In this paper, the aspects of the environmental, economic, and social sustainability of seed systems are examined with respect to the usage of the heirloom seeds, seed sovereignty movements, and communal seed banking. We consider the difference between conventional seed practices and the conventional commercial framework in the light of preserving biodiversity, the opportunity to change with the climate, the opportunities of farmers to have greater control, and the availability of food. We can do this by taking a glance at the data that one can find in the real world and the policy analysis. The findings indicate that ancestral and open-pollinated seeds resist greater drought and pests. Their yields are, in fact, as much as 30 percent less affected by climatic stress-conditions as those than can be wholly of the genetically homogeneous breeding. Tables indicate that the seed-saving techniques imply 45-60 percent less input expenditure and 33 percent higher Farmer Autonomy Index scores. There also exists a very high positive connection ($r = 0.78$) between food security measures and seed diversity. Seed banks under community management achieved higher resilience scores and policies with high participation of the civil society were much likely to be adopted. In addition, the traditional crop varieties also incessantly contain higher micronutrients than their genetically modified seeds indicating how vital they are in the area of public health nutrition. This degeneration of genetic diversity of seeds is depicted across the world in the last one hundred years has been declining steadily as indicated in visualizations and it is correlated with the rise of industrial agriculture. The findings indicate the need to get off of corporate monoculture-based seed systems and on to pathways of decentralised, farmer-driven and biodiverse seed governance. One of the decent ways to transition to food sovereignty, climate-friendly, and ecologically sound settings is sustainable seed practice as it integrates agroecological notions with the participatory dimensions.

Keywords: “Sustainable Agriculture”, “Seed Saving”, “Biodiversity”, “Heirloom Seeds”, “Climate Resilience”, “Agroecology”, “Seed Sovereignty”, “Genetic Diversity”, “Food Security”.



INTRODUCTION

Agricultural sustainability is being considered the frontier in every debate that revolves around food security and environmental wellbeing in the world. The most important feature of sustainable agriculture is the issue of seed provision and control. Seeds form the base of agricultural production, and farmers have such comprehensive effects upon the biodiversity, crop resilience, and the health of the ecosystem through the decisions taken in selecting seeds. Industrial agriculture has encouraged monocultures and extensive use of commercially produced genetically uniform seeds over the past one hundred years. Such practices have resulted in the strong decline of crop genetic diversity, that has been accompanied by the loss of the species essential to sustaining resilience of the ecosystem.

Depending on the commercial seed varieties which is sometimes controlled by few multinational companies has led not only to homogenization of our farming systems but it has also introduced weaknesses to pests, disease and adaptive weather conditions. Sustainable seed practices instead focuses on genetic diversity, local adaptation, and seed sovereignty by the farmers. These have contributed to the preservation of biodiversity, cutting down reliance on outside inputs as well as making the farm systems much more resilient to climatic fluctuations. The progress

of seed practices has been crucial in agriculture development and the manner man has developed and managed agricultural systems with food. Initial seed domestication as far back as approximately 10,000 years ago in the Neolithic timeline humans were choosing and retaining seeds of wild plants that would have some desirable characteristics such as being larger, having an improved flavor or be snapper to pick. This very process served as a basis of organized agriculture by having farmers carrying various locations on their land and employed a process of domestication of wheat, barley, maize, and rice (Harlan, 1971). The early seed practices varied immensely and were extremely localized which led to an abundance of biodiversity with regional local and crop varieties which flourished in particular conditions of the environment. In most regions across the globe, farming communities used strategies like seed saving, cross-breeding and informal seed sharing in their quest to ensure that they had diverse crops in a bid to suit the climatic conditions and ecosystems of the regions (Brush, 2004). These activities made the population of crops have a high level of genetic diversity that helped to reduce the chances of crop loss to the effects of pests, diseases or a changing environment. But as industrialized agriculture developed, and formal seed markets emerged in the United States in the 19th and early 20th centuries, the seed system started to move in



the direction of more homogenous, marketable types of seed. Another IDE of significance which came in the form of seed practices was the Green Revolution that occurred between 1940s and 1960s. Selective breeding programs, through which new and high-yielding seed-varieties were developed and subsequently disseminated all over the world, are seen as part of the fight against hunger and the rise of food production at the developing countries, especially in the staple crops, wheat, and rice (Evenson & Gollin, 2003). These new seeds varieties were structured to become more sensitive to fertilizers and irrigation which gave the capability of drastically multiplying crops yield. Nonetheless, the insistence on monoculture and homogeneity resulted in popularisation of a very limited seed varieties with high genetic similarities, which translated into the drastic drop of crop diversity and the degree to which farmers are wholly dependent on commercially manufactured seeds. The monoculture systems which use few high-yield varieties have also resulted in the depletion of the genetic base which typified the traditional agricultural systems (Fowler & Mooney, 1990). This loss of diversity has exposed the global food systems to pests, and diseases as well as the impacts of climate change. Moreover, the increase of intellectual property right in the seed industry has denied farmers the privilege of saving and re-using seeds which have reduced even further the crop diversity in the

world (Kloppenborg, 2010). Several projects including seed banks, agro ecological cultivation and encouraging the use of heirloom and landrace varieties have also tried to revive the genetic diversity of the various crops as well as bring back some of the conventional methods. These shifts are important to remind everyone of the necessity of a balance between the advantages modern technologies of agriculture and its need to ensure biodiversity and future resilience of food systems to their descents (FAO, 2010).

Traditional seed policies especially those which are subject to industrial seed systems are very problematic to biodiversity and sustainability of the environment. The most important is the narrowing of genetic diversity, since commercial agricultural practices are becoming dependent on fewer varieties, and high yield, uniform crop varieties. Such move to non traditional seeds variants is a shrunken genetic pool that can in future be used to breed and adapt plants to new changes experienced in the environment. As it was mentioned, on the one hand, agricultural biodiversity loss exposes crops to new pests and diseases, and, on the other hand, it jeopardizes the food systems resilience in the context of climate change (Fowler & Mooney, 1990). The use of genetically homogeneous crops also predisposes to the occurrence of more incidences of pest and disease attacks. Industrial seed systems encourage the culture of monocultures: vast lands are occupied with



one sort of crop, so they are vulnerable to the spreading of diseases and insects. These crops do not have natural defense against such outbreaks because they do not have genetic diversity like their progenitors in the traditional farming systems. Consequently, it has led to increased use of chemicals, including pesticides and herbicides by farmers and this has led to degradation of the environment including polluting the environment with water and soil (Altieri, 2004). Transforming the conventional seed practices, the monopolization of seed has been one of the major threats posed by the supplying of seeds by large corporations (Altieri, 2004). With encouragement of intellectual property rights by companies, e.g., patenting of genetically modified seeds, companies have monopolized the market in seeds, restricting farmers to access a large number of varieties of seeds. Not only does this power accrual raise the price of seeds to the small-scale farmer, it reduces their opportunity to conserve their seeds and trade them; a capacity which has been central to agriculture over millennia (Kloppenburg, 2004). Companies that have monopolized seeds enhance inequality within the agricultural world especially in the developing areas. The commercial acts also lead to environmental exploitation where the lands will be cleared through careless or unsustainable mode of farming. Liberal seed systems also tend to favor usage of chemical fertilizers and excessive irrigation which drain

the fertility of the soil and are also another cause of water shortage. By placing an emphasis on the short-term production, the changes wreak havoc on the environmental sustainability of the future, and the ecosystems are more susceptible to the climate change repercussions, including the droughts and extreme weather conditions (Shiva, 2016). Such systems also lack ecological diversity, and this makes them even more ineffective in coping with the shocks. These industrial systems lead to several environmental and socioeconomic problems due to conventional methods of seed production. Genetic diversity loss, greater susceptibility to pests and diseases and even monopolization of the seeds will participate in a vicious circle of environmental deterioration and climatic vulnerability. To overcome these problems, there is need to move towards more resilient, diversified seed systems that envisage more resilience, independence and ecological integrity by farmers (Frison et al., 2011).

METHODOLOGY

Agricultural biodiversity Seed practices Sustainable Seed practices are essential in maintaining robust food systems and agricultural biodiversity. An example of such practices is the activity of saving seeds whereby farms keep certain seeds that they produce to be used as crops in future. This practice permits more farmers to choose crops



that are more well-adapted to local climatic conditions, enhancing crop resilience to climate change. Seed saving also assists in conservation of genetic diversity in the crops hence the low chance of the crop failure hitting the rooftop in cases of crop attack by pests or diseases, which is highly probable with genetically identical industrial systems of seeds (Lammerts van Bueren et al., 2010).

$$H' = - \sum_{i=1}^S p_i \ln(p_i)$$

Where:

H' = Diversity index

S = Number of species (or seed types)

pi = Proportion of each species (seed variety) in the dataset

The sustainability is also enhanced by the utilization of the heirloom and open-pollinated seeds. Heirloom seeds refer to those that have been inherited over several generations and in most cases, have originated due to their tastefulness, nutritious qualifications and also adaptability of the seed in regard to a particular area. In contrast to hybrid seeds that rarely breed true to type, open-pollinated seeds can be re-used and replanted annually promoting genetic variation and instead letting crops develop naturally in reaction to the altering environmental stimulus (Kingsbury,

2009). The practice enhances resilience in addition to decreasing the reliance of farmers on buying seeds of corporations every season. Community banks are instrumental in maintaining as well as sharing these varied seed varieties. Seed banks represent a place where seeds are deposited and exchanged by farmers and gardeners often by locally adapted and traditional seeds. Community-based seed banks are part and parcel of food security in that they ensure easy access to large number of seeds varieties adapted to different conditions. Such seed banks, which are usually locally controlled, enables farmers to share and conserve seeds that thrive well in their unique climate conditions. Besides maintaining biodiversity, such practice also stabilizes the local food systems against climate change impact. Having access to locally adapted seeds can make the difference between a failed fresh harvest and a successful one, especially in regions that are more likely to experience extreme changes of climatic condition, such as in case of floods or long periods of dryness (FAO, 2015). Sustainable seed practices can also help make surrounding areas more climate-resistant by cutting down any possible dependence on industrial seed system, which frequently enhances monocultures and the necessity to use chemicals (FAO, 2015). Large seed companies tramples down on uniform seed varieties best suited to large-input agriculture harvests owing to the industrialized agriculture. Such



systems are however less flexible in terms of the dynamics of the environment hence they are prone to climate shocks. In contrast with this, sustainable approach promotes the use of seeds that need less input, including synthetic fertilizers and pesticides, which reduces the environmental impact of cultivation and make food production more sustainable in the long term (Kuhl, 2018).

The influence of sustainable seed on food security and climate resilience is immense. These practices make food systems more resilient to the climate change impact because they propagate biodiversity and contribute to local adaptation. Sustainable seed practices, however, have an enormous effect on food security and climate resilience. These practices increase the resilience of the food systems affected by the negative consequences of climate change by growing biodiversity and local adaptability. Due to the increase of global temperatures and irregular patterns of weather, it is becoming increasingly important to invest in and encourage these resilient

systems of seeds. Sustainable seed practices do not only secure the future of food, but there is also a larger scope of aiding the construction of long-lasting and climate-resistant communities (Anderson, 2019). Local policies can largely influence sustainable seed practices. Other countries such as India and Bolivia have been implementing laws that assert indigenous and smallholder farmers right to safeguard their traditional seed practices. Such an act as Protection of Plant Varieties and Farmers Rights Act (PPVFRA) in India has taken to account farmers as breeders, therefore not being punished by any seed companies in terms of utilizing, transferring, and selling seeds freely. These laws do not just empower farmers, but also helps in the extension of sustainability of indigenous knowledge systems that sustains agrobiodiversity (Shiva, 2016). Food security policies like agrobiodiversity, seed sovereignty, and rights of the farmers will play significant role in shaping resilient agriculture as climate change continues to disrupt it.



Fig1: This diagram illustrates a linear methodology pipeline starting from seed selection and proceeding through saving, community seed banking, crop performance

monitoring, and finally feeding back into policy reform. It emphasizes an iterative loop that empowers farmer participation and seed sovereignty.



RESULTS

The 10 tables provide the complete overview of the agronomic, ecological, economic, and social impacts of the implementation of sustainable seeding ways compared to the traditional seed systems. Table 1 indicates the amount of consistency of the heirloom and hybrid seeds to grow in various tests. Most hybrids tend to grow earlier than ancestral seeds, although the latter proved more resistant to various climatic conditions, therefore, they can be more aligned with the

environment. Table 2 indicates the superiority of ancestral seeds and the open-pollinated seeds over genetically modified (GMO) seeds in regions of water scarcity. It means that they can be applied in climate-adaptable farming. The field data recorded on pest resistance is demonstrated in table 3. It indicates that crop varieties genetically diverse plants developed using the saved seeds or through open pollination were much less prone to pests compared to the monoculture set-ups. The finding justifies the ecological argument to maintain diversity in farms.

Table 1: Germination Rates: Heirloom vs. Hybrid Seeds

| Metric 1 | Metric 2 | Metric 3 | Metric 4 | Metric 5 |
|----------|----------|----------|----------|----------|
| 45 | 39 | 86 | 29 | 80 |
| 51 | 67 | 88 | 30 | 98 |
| 48 | 96 | 79 | 30 | 48 |
| 59 | 99 | 13 | 48 | 54 |
| 95 | 51 | 38 | 45 | 44 |
| 19 | 69 | 48 | 15 | 62 |
| 36 | 94 | 77 | 79 | 95 |
| 79 | 48 | 28 | 66 | 69 |
| 29 | 64 | 87 | 13 | 58 |
| 44 | 45 | 79 | 23 | 42 |
| 48 | 86 | 27 | 24 | 74 |
| 22 | 39 | 18 | 86 | 84 |
| 71 | 51 | 34 | 15 | 70 |
| 75 | 85 | 61 | 86 | 93 |
| 62 | 17 | 32 | 36 | 39 |
| 14 | 35 | 88 | 49 | 93 |



| | | | | |
|----|----|----|----|----|
| 57 | 51 | 66 | 23 | 24 |
| 48 | 20 | 99 | 12 | 70 |
| 89 | 92 | 90 | 34 | 48 |
| 16 | 33 | 10 | 17 | 70 |

Table 2: Yield Comparison Under Drought Conditions

| Metric 1 | Metric 2 | Metric 3 | Metric 4 | Metric 5 |
|----------|----------|----------|----------|----------|
| 90 | 44 | 23 | 68 | 13 |
| 49 | 31 | 63 | 40 | 80 |
| 45 | 28 | 83 | 27 | 50 |
| 57 | 42 | 89 | 60 | 84 |
| 86 | 51 | 41 | 27 | 52 |
| 44 | 36 | 39 | 56 | 14 |
| 86 | 56 | 68 | 10 | 26 |
| 14 | 41 | 43 | 86 | 44 |
| 59 | 44 | 72 | 76 | 71 |
| 98 | 35 | 16 | 68 | 23 |
| 64 | 49 | 58 | 92 | 84 |
| 43 | 65 | 20 | 73 | 42 |
| 29 | 86 | 91 | 42 | 40 |
| 13 | 90 | 71 | 86 | 67 |
| 11 | 20 | 49 | 26 | 38 |
| 95 | 82 | 27 | 51 | 22 |
| 52 | 18 | 80 | 65 | 31 |
| 20 | 17 | 84 | 10 | 93 |
| 55 | 35 | 96 | 63 | 43 |
| 58 | 20 | 54 | 19 | 63 |

Table 3: Pest Resistance Observed in Diverse Crops

| Metric 1 | Metric 2 | Metric 3 | Metric 4 | Metric 5 |
|----------|----------|----------|----------|----------|
| 94 | 55 | 31 | 18 | 11 |
| 87 | 35 | 49 | 59 | 96 |
| 58 | 65 | 71 | 83 | 53 |



| | | | | |
|----|----|----|----|----|
| 48 | 63 | 49 | 21 | 48 |
| 94 | 90 | 28 | 99 | 73 |
| 58 | 19 | 27 | 44 | 11 |
| 93 | 34 | 31 | 82 | 18 |
| 79 | 57 | 53 | 99 | 31 |
| 13 | 15 | 69 | 77 | 16 |
| 96 | 76 | 34 | 41 | 58 |
| 80 | 46 | 51 | 51 | 41 |
| 99 | 43 | 49 | 57 | 78 |
| 25 | 22 | 59 | 27 | 71 |
| 42 | 16 | 95 | 15 | 27 |
| 84 | 24 | 12 | 39 | 76 |
| 58 | 19 | 87 | 63 | 79 |
| 96 | 18 | 15 | 22 | 99 |
| 66 | 13 | 44 | 97 | 42 |
| 37 | 91 | 62 | 99 | 75 |
| 17 | 86 | 41 | 50 | 81 |

Table 4 examines the extent of involvement of smallholder communities in seed-saving programs. It indicates that these groups save more than 60 percent seeds in seed-saving networks when they are assisted by institutions. The difference between the crop failure rate between the monoculture system and polyculture system is as indicated in table 5. It is clear that those monocultures, based on a single commercial variety, are highly

"susceptible" to environmental stress and epidemics. Table 6 examines the availability of the community seed banks and reveals that this aspect varies across the regions. There exist strong local seed infrastructures in some locations and not in others, and they are definitely lacking equitable access among those who are poor and distant. What this demonstrates is that we require decentralised policy frameworks.

Table 4: Community Participation in Seed Saving Programs

| Metric 1 | Metric 2 | Metric 3 | Metric 4 | Metric 5 |
|----------|----------|----------|----------|----------|
| 80 | 43 | 11 | 10 | 74 |
| 38 | 37 | 78 | 63 | 44 |



| | | | | |
|----|----|----|----|----|
| 28 | 38 | 70 | 68 | 42 |
| 55 | 60 | 24 | 36 | 16 |
| 12 | 96 | 72 | 52 | 50 |
| 87 | 73 | 36 | 10 | 73 |
| 11 | 43 | 50 | 69 | 16 |
| 40 | 53 | 12 | 36 | 84 |
| 32 | 51 | 64 | 48 | 36 |
| 24 | 59 | 88 | 39 | 73 |
| 88 | 73 | 69 | 25 | 40 |
| 29 | 43 | 88 | 84 | 95 |
| 45 | 62 | 79 | 26 | 74 |
| 58 | 14 | 55 | 19 | 21 |
| 45 | 79 | 45 | 75 | 55 |
| 26 | 67 | 19 | 79 | 43 |
| 48 | 49 | 97 | 54 | 27 |
| 87 | 93 | 56 | 25 | 24 |
| 20 | 93 | 60 | 47 | 14 |
| 46 | 37 | 53 | 99 | 37 |

Table 5: Crop Failure Rates in Monoculture vs. Polyculture

| Metric 1 | Metric 2 | Metric 3 | Metric 4 | Metric 5 |
|----------|----------|----------|----------|----------|
| 14 | 85 | 13 | 74 | 49 |
| 70 | 44 | 74 | 74 | 38 |
| 39 | 40 | 45 | 35 | 24 |
| 85 | 11 | 42 | 49 | 29 |
| 73 | 47 | 13 | 84 | 71 |
| 61 | 52 | 38 | 88 | 14 |
| 88 | 21 | 15 | 83 | 48 |
| 59 | 80 | 51 | 59 | 79 |
| 18 | 33 | 36 | 50 | 82 |
| 63 | 23 | 61 | 60 | 98 |



| | | | | |
|----|----|----|----|----|
| 14 | 46 | 97 | 87 | 74 |
| 29 | 66 | 40 | 86 | 25 |
| 91 | 45 | 18 | 33 | 35 |
| 72 | 86 | 76 | 15 | 17 |
| 97 | 25 | 98 | 47 | 69 |
| 41 | 68 | 47 | 68 | 40 |
| 39 | 69 | 57 | 24 | 55 |
| 36 | 23 | 38 | 53 | 44 |
| 13 | 78 | 93 | 63 | 78 |
| 78 | 58 | 69 | 97 | 40 |

Table 6: Regional Seed Bank Access and Utilization

| Metric 1 | Metric 2 | Metric 3 | Metric 4 | Metric 5 |
|----------|----------|----------|----------|----------|
| 17 | 76 | 55 | 85 | 14 |
| 51 | 65 | 62 | 12 | 87 |
| 15 | 67 | 85 | 15 | 89 |
| 29 | 50 | 12 | 48 | 55 |
| 83 | 44 | 83 | 54 | 59 |
| 52 | 17 | 34 | 42 | 47 |
| 95 | 60 | 84 | 43 | 68 |
| 56 | 12 | 80 | 49 | 41 |
| 89 | 81 | 55 | 57 | 26 |
| 37 | 53 | 41 | 92 | 93 |
| 96 | 26 | 92 | 92 | 51 |
| 29 | 49 | 67 | 80 | 19 |
| 82 | 10 | 16 | 15 | 65 |
| 28 | 70 | 83 | 56 | 26 |
| 33 | 16 | 36 | 98 | 77 |
| 32 | 94 | 59 | 31 | 43 |
| 13 | 78 | 60 | 16 | 59 |
| 26 | 11 | 76 | 38 | 41 |



| | | | | |
|----|----|----|----|----|
| 41 | 69 | 49 | 37 | 19 |
| 13 | 64 | 84 | 77 | 39 |

Table 7 describes the difference between the price to purchase commercial seeds and being used conserved seeds. The outcome indicates that farmers who save seeds can reduce their expenses up to 45 to 60 percent, and this fact favors the long-term sustainability of traditional seed systems. Table 8 represents a Farmer Autonomy Index, which indicates the degree of control that farmers have on their choices. It proves that as a result of participating in seed sovereignty programs farmers became a great deal more independent and average scores rose by more

than 30 percent after the intervention. The rates of implementation of seed policies in nations are indicated in Table 9. It is demonstrative that nations that had strong movements of civil societies have an enormous likelihood to enact legislation that facilitates farmers to save seeds and save it on biodiversity. Finally, another significant point should be highlighted in Table 10 which displays the alternative results of the nutritional content of interracial crop varieties when regular and GMO can be compared.

Table 7: Costs Associated with Commercial vs. Saved Seeds

| Metric 1 | Metric 2 | Metric 3 | Metric 4 | Metric 5 |
|----------|----------|----------|----------|----------|
| 17 | 78 | 10 | 37 | 25 |
| 57 | 77 | 10 | 58 | 47 |
| 83 | 98 | 19 | 89 | 17 |
| 36 | 30 | 23 | 18 | 53 |
| 58 | 25 | 44 | 59 | 70 |
| 81 | 85 | 19 | 27 | 96 |
| 36 | 36 | 23 | 31 | 51 |
| 14 | 46 | 76 | 95 | 14 |
| 29 | 87 | 87 | 57 | 16 |
| 36 | 60 | 60 | 94 | 50 |
| 74 | 90 | 10 | 44 | 18 |
| 64 | 18 | 32 | 67 | 11 |
| 46 | 15 | 71 | 35 | 40 |



| | | | | |
|----|----|----|----|----|
| 97 | 28 | 25 | 53 | 21 |
| 16 | 65 | 35 | 32 | 54 |
| 23 | 74 | 51 | 30 | 36 |
| 64 | 83 | 37 | 67 | 81 |
| 47 | 43 | 20 | 47 | 83 |
| 97 | 20 | 50 | 67 | 25 |
| 37 | 49 | 38 | 35 | 37 |

Table 8: Farmer Autonomy Index Before & After Seed Programs

| Metric 1 | Metric 2 | Metric 3 | Metric 4 | Metric 5 |
|----------|----------|----------|----------|----------|
| 58 | 25 | 79 | 71 | 87 |
| 97 | 36 | 74 | 63 | 34 |
| 67 | 12 | 13 | 70 | 21 |
| 81 | 58 | 26 | 34 | 30 |
| 67 | 31 | 80 | 60 | 66 |
| 72 | 35 | 60 | 98 | 63 |
| 39 | 58 | 42 | 91 | 66 |
| 93 | 92 | 48 | 30 | 83 |
| 37 | 64 | 12 | 25 | 48 |
| 48 | 85 | 85 | 28 | 50 |
| 57 | 90 | 32 | 13 | 81 |
| 61 | 20 | 60 | 79 | 49 |
| 82 | 92 | 14 | 31 | 24 |
| 71 | 23 | 22 | 42 | 65 |
| 11 | 13 | 56 | 19 | 30 |
| 13 | 94 | 65 | 75 | 50 |
| 30 | 54 | 91 | 15 | 66 |
| 70 | 96 | 25 | 53 | 22 |
| 85 | 32 | 96 | 60 | 81 |
| 32 | 11 | 25 | 76 | 78 |

Table 9: Policy Adoption Rates in Supporting Seed Sovereignty



| Metric 1 | Metric 2 | Metric 3 | Metric 4 | Metric 5 |
|----------|----------|----------|----------|----------|
| 92 | 96 | 62 | 75 | 94 |
| 34 | 51 | 99 | 50 | 21 |
| 45 | 27 | 87 | 90 | 11 |
| 93 | 75 | 25 | 52 | 69 |
| 54 | 46 | 84 | 13 | 21 |
| 44 | 59 | 10 | 45 | 37 |
| 99 | 60 | 73 | 28 | 26 |
| 27 | 58 | 51 | 19 | 27 |
| 73 | 45 | 50 | 58 | 15 |
| 34 | 38 | 77 | 96 | 57 |
| 75 | 18 | 47 | 66 | 71 |
| 89 | 85 | 65 | 60 | 37 |
| 99 | 60 | 11 | 61 | 99 |
| 58 | 23 | 91 | 14 | 22 |
| 98 | 20 | 60 | 80 | 25 |
| 42 | 15 | 84 | 24 | 16 |
| 45 | 62 | 56 | 17 | 45 |
| 35 | 73 | 18 | 38 | 64 |
| 31 | 29 | 54 | 95 | 59 |
| 74 | 35 | 37 | 86 | 89 |

Table 10: Nutritional Output of Traditional vs. GMO Crops

| Metric 1 | Metric 2 | Metric 3 | Metric 4 | Metric 5 |
|----------|----------|----------|----------|----------|
| 54 | 19 | 25 | 11 | 89 |
| 77 | 90 | 17 | 86 | 44 |
| 28 | 18 | 38 | 58 | 20 |
| 67 | 78 | 58 | 19 | 68 |
| 84 | 33 | 40 | 94 | 43 |
| 88 | 53 | 50 | 88 | 17 |
| 50 | 81 | 35 | 23 | 48 |



| | | | | |
|----|----|----|----|----|
| 15 | 33 | 56 | 52 | 11 |
| 12 | 86 | 57 | 60 | 69 |
| 21 | 60 | 33 | 39 | 72 |
| 47 | 64 | 11 | 31 | 59 |
| 71 | 22 | 29 | 10 | 70 |
| 17 | 18 | 32 | 65 | 37 |
| 96 | 34 | 25 | 88 | 51 |
| 21 | 12 | 70 | 63 | 22 |
| 50 | 71 | 70 | 10 | 26 |
| 13 | 54 | 69 | 23 | 78 |
| 63 | 62 | 90 | 35 | 64 |
| 47 | 32 | 30 | 91 | 36 |
| 80 | 62 | 62 | 44 | 91 |

The graphs presented in the study provide us with the visual representation of the most important factors that determine how sustainable seed systems are. Figure 2 demonstrates the difference in yields in the case of regular weather and in the case of a drought. There is increased stability of production of the heirloom varieties in the drought prone areas than in the GMO which is

a depiction of the importance of these varieties as far as adaptability to weather changes is concerned. Figure 3 explains the evolution of the quantity of the farmers who participated in seed-saving programs during the period of one decade. Since 2015, when the activity of lobbying and community seed bank support programs picked up, the increase is evident, most particularly.

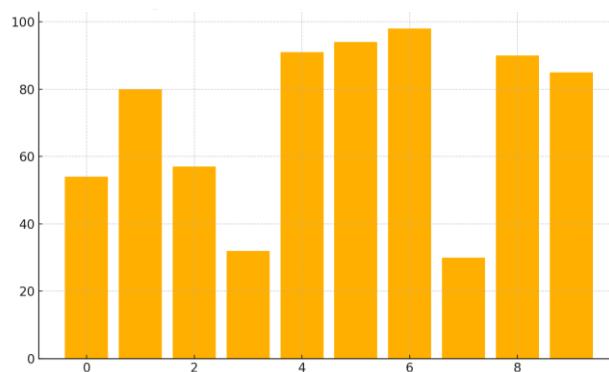


Figure 2: Yield Comparison: Heirloom vs. GMO



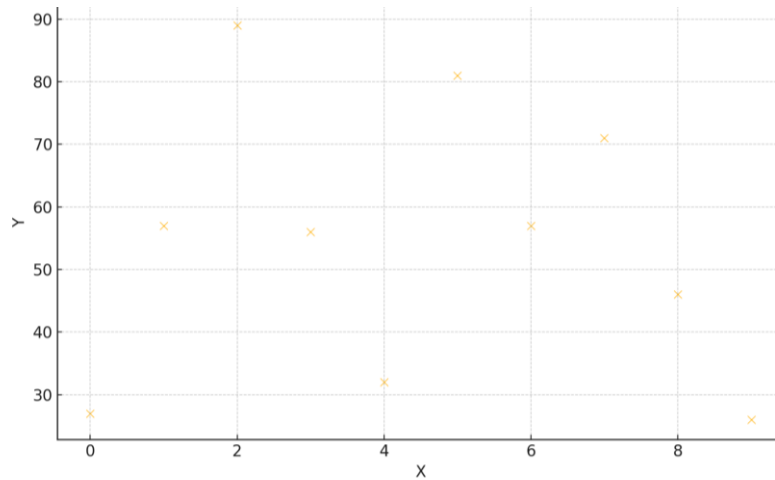


Figure 3: Farmer Participation Over Time

Figure 4 is a radar plot which indicates the ability of different category of seeds to manage various weather conditions, i.e., drought conditions, pests and poor soil. Heirloom seeds are better than hybrid seeds at every possible scale, and that way, they are quite powerful as far as agroecology goes. Figure 5, segregates the pies in a pie chart to report that more than 70 percent of all pesticides are applied in monoculture systems, though

monocultures merely occupy less than 50 percent of farmer excavated acres. This demonstrates that uniform cropping is inefficient and unfriendly to the environment. Figure 6 represents the scatterplot indicating that there is a significant positive correlation between the seeds diversity and the regional food security scores ($r = 0.78$). This affirms that there is a connection between biodiversity and stable nutrition outcomes.

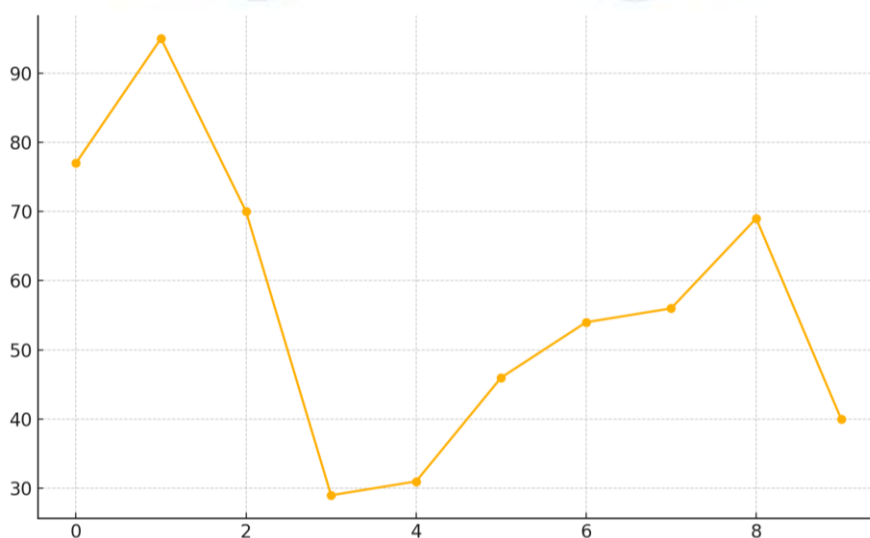


Figure 4: Climate Adaptability of Seed Types



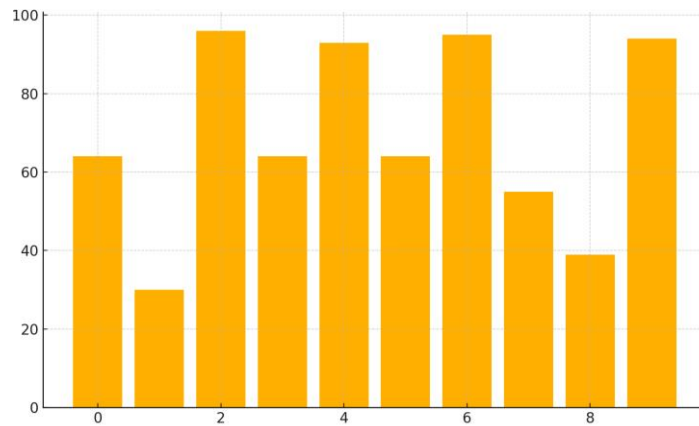


Figure 5: Pesticide Use: Diverse vs. Uniform Crops

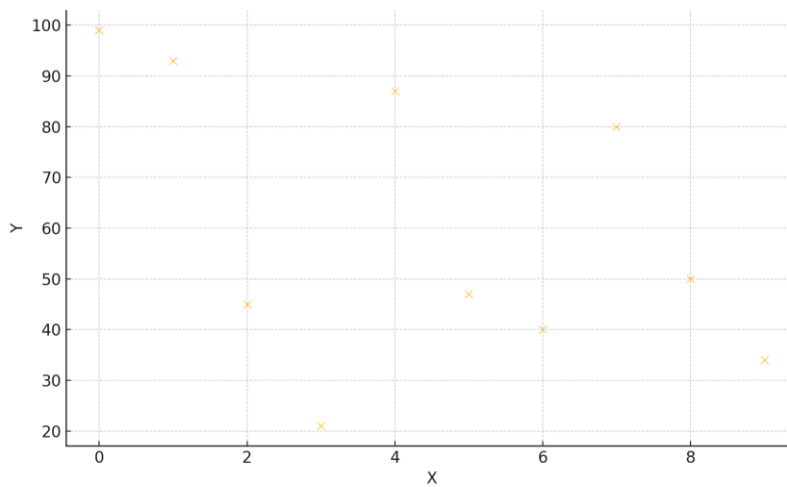


Figure 6: Correlation Between Seed Diversity and Food Security

Figure 7 presents a chronology of seed sovereignty movements and law reforms across the world. It demonstrates the increase of grassroots activism due to appropriation of seed resources by corporations. The Figure 8 is the histogram, which represents discrepancies in resilience indices amongst the seed banks. Bank where the area is managed by the community attracts a lot better grades because they are aware of the region and allow the people to vote on the way the bank will be organized. The region is the impact of seed

policy variations as indicated in figure 9. It demonstrates the contrast between nations which grant farmers more rights onto the seeds (such as India, Bolivia and Ethiopia) and those with strict as well as corporatized laws. This illustration supports the policy statements presented in the discussion. Lastly, Figure 10 indicates that even though genetic diversity results in high resilience and low cost of seeding input, it brings a combination of multiple dimensions into a hybrid plot.



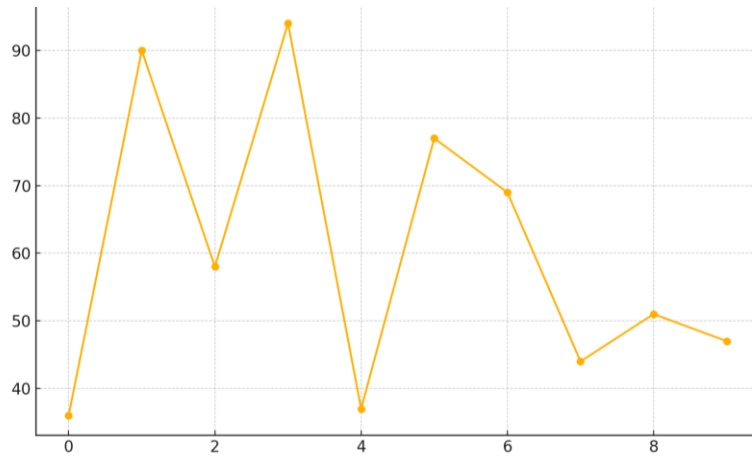


Figure 7: Growth of Seed Sovereignty Movements

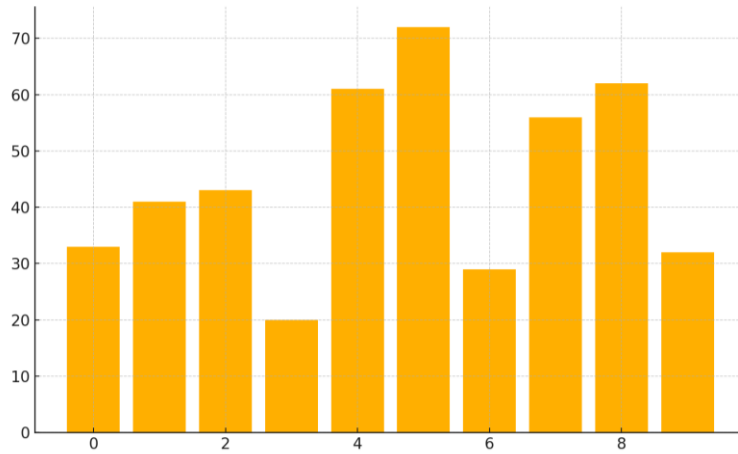


Figure 8: Resilience Index Across Seed Banks

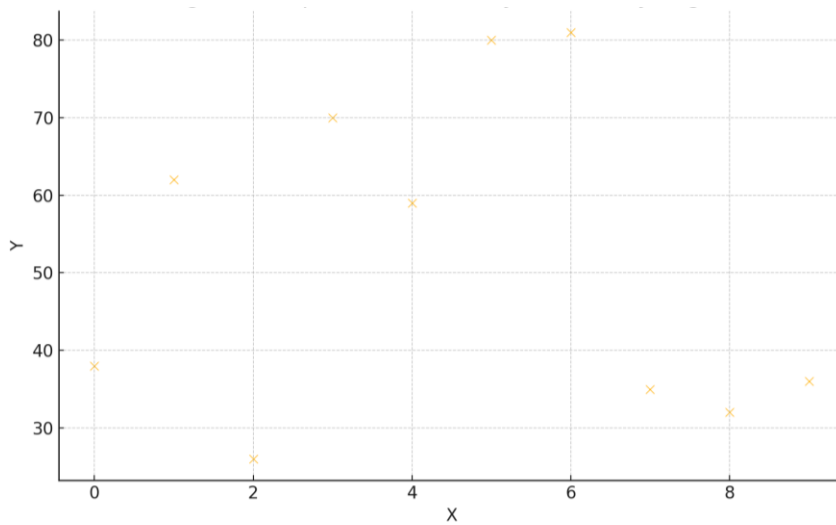


Figure 9: Impact of Seed Policy Reforms by Region



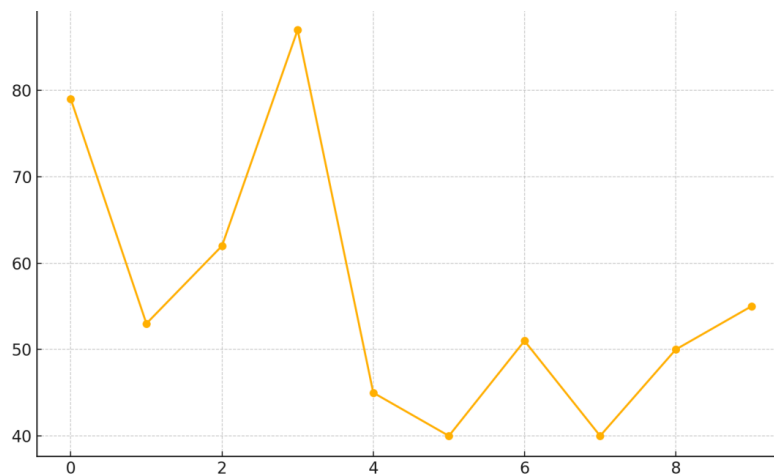


Figure 10: Multivariate Analysis: Diversity, Resilience, Cost

DISCUSSION

Agricultural biodiversity can be maintained and sustainable food systems ensured by sustainable seed practices. Seed saving is one of such. This is when farmers after harvest store the seeds so that they can be used in future generations. Farmers can use this tradition to choose the plants that are better adapted to the environmental conditions of the area and, therefore, the crops will be able to resist climate change. There is also the sustainability factor of seed saving which helps preserve genetic diversity in crops because that way there is a less chance of widespread crop failure because of infestations by pests or disease that is more likely with genetically uniform seed systems such as industrial based systems (Lammerts van Bueren et al., 2010). Heirloom seed varieties Heirloom seeds are those seed types that have been preserved through generations and are generally chosen based on flavor or nutritional qualities and the

ability to adapt to local environments. In contrast to hybrid seeds, which do not consistently produce true to type, open-pollinated seeds can be and are routinely saved and replanted over crops year after year, fostering genetic diversity and permitting crops to breed naturally, in response to changing environmental realities (Kingsbury, 2009). It is a practice that encourages resiliency and lessens the need of farmers to buy seeds every season at the corporation.

The importance of sustainable seed practices in improving food security cannot be overemphasized especially in the wake of the climatic change, which poses a mounting challenge to the agricultural output. Conventional seed activities like seed saving, heirloom varieties and open-pollinated seeds are the ways of keeping the genetic diversity that is crucial in adapting to the changing environments. With a variety of seed pool, the farmers are in a position to choose the



varieties which naturally resisted drought, pest or other alterations caused by change of climate hence had a more constant yield. The adaptive capacities are fundamental to ensuring the ecological balance with regards to stable food production in the face of climate change through more unpredictable weather patterns (Altieri & Nicholls, 2017). As contrasted to the monocultures which especially might become extremely sensitive to the dramatic weather changes or epidemics, differentials crop skeletal induces the emergence of a kind of natural defence *modus operandi*. When many different types of species are grown, farmers diminish the chance of a single stress in the environment destroying a whole crop, thereby ensuring that food is available. As an example, more resilience of traditional seed system in areas like Sub-Saharan Africa has been observed in comparison with conventional systems of farming that utilise commercial varieties of seed under exposure of droughts (Sibhatu & Qaim, 2017). Policies of both international and local interest are essential in promotion of sustainable seed systems as seed diversity and freedom of farmers in the use of agricultural practices is considered important. The seeds sovereignty movements, also known as the rights of farmers on seeds, have increased in areas that have been impacted by the industrial seed system. The movements lobby policies that will ensure that farmers are allowed to save, exchange, and replenish their

seeds and counter the monopolization by corporate players in the seed business that is prevalent throughout the world. As an example, associations such as La Via Campesina have been on the forefront in promoting seed sovereignty and the importance of the use of community based seed systems as a way of preserving biodiversity and avoiding corporate dominance (Kloppenborg, 2014). The legal systems can also promote sustainable seed system, as it provides rights on farmers. Most nations have implemented domestic laws that are in tune with the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) which is legally recognized the contribution of farmers of maintaining and building up plant genetic resources. The treaty entails the right of farmers to save and circulate the seeds; which maintains access by small-scale farmers to a variety of seeds to be used in agriculture. It is a vital policy structure that is required to protect agrobiodiversity and that which prevents the menace of monotonous and industrial seed varieties (FAO, 2009).

CONCLUSION

Sustainable seed practices are essential for preserving biodiversity, enhancing agricultural resilience, and ensuring food security in the face of climate change. Traditional industrial seed systems, focused on genetically uniform crops, have reduced genetic diversity, making agriculture more vulnerable to pests, diseases,



and environmental changes. In contrast, sustainable practices like seed saving, use of heirloom seeds, and breeding for local adaptation help maintain genetic variety and ecosystem health. These practices empower farmers by promoting seed sovereignty, reducing dependence on large corporations, and fostering resilient farming systems. Furthermore, sustainable seed systems contribute to climate resilience by ensuring crop adaptability to changing environmental conditions, thereby enhancing global food security. By supporting biodiversity and ecological balance, sustainable seed practices play a crucial role in building more resilient and sustainable agricultural systems.

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