Chapter 5
The Decline of Agrobiodiversity: Process of Crop Improvement, Consequent Homogenization, and Impacts

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Abbreviations

GM genetically modified
HYV high-yielding varieties

5.1 Introduction

Agricultural biodiversity or agrobiodiversity, in simple terms, implies the diversity in various ways, richness, evenness, or divergence, of edible flora and fauna. In other words, it is also invoked to refer to the vast number of varieties and variability of living organisms that not only contribute to food and agriculture but also to the knowledge associated with them (Thrupp 2000). In a more inclusive sense, agricultural biodiversity does not only encompass the various forms (varieties, breeds, species) of living organisms essential for food, fiber, fodder, fuel, and pharmaceuticals but also the larger adjoining ecosystems (agricultural, pastoral, forest, aquatic or fallow) that closely support their production. Therefore, it includes wild uncultivated edible (edible flora and fauna which are not under an organized cultivation regime) and non-edible species (numerous pollinators, millions of macro- and microbiota of soil), and other associated landscape elements (hedges, pastures, perennial and non-perennial aquatic bodies, marshes, fallow, etc.) that shelter them (FAO 1999). Also vital is the traditional agroecological knowledge of the farmers or associated key persons which is viewed as an indispensable component of the farming systems (Argumedo 2008; Koohafkan and Altieri 2011).

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It is the interplay of natural selection, random genetic drift, migration, and mutation that co-act with the creation of diversity; it was also shaped by the artificial human-mediated selection and cultivation by farmers and gatherers, herders and fishers who used to maintain and utilize that diversity over millennia (Frankel et al. 1995; Hancock 1992; Hufford et al. 2019). So, they remain at the center of agrobiodiversity creation and management, make use of them and garner a rich body of knowledge that imbibed key information about the know-how of employing and exploiting the specific properties of the cultivated or non-cultivated genetic materials. Thus, most farmers play an important role in the flow of genetic materials and in strengthening the on-farm conservation, diversity deployment, seed supply system, conservation, and training (Subedi et al. 2003). Globally, there has been a growing recognition of traditional knowledge systems and their potential role in tackling the climate crisis (Anon 2022; Forest Peoples Programme 2020). So, the notions of agricultural biodiversity tend to expand from a narrow delimitation of edible species diversity and embrace the larger systems with multiple components essential to sustain food and agriculture.

Agrobiodiversity is the bedrock of agricultural production that sustains, can improve human nutrition, and provide sources of medicines and vitamins. Decades of intensive research and analyses have demonstrated that agrobiodiversity has a key role in the functioning of ecological systems, conserving ecosystem structure, the generation of a vast array of services, rendering farming systems more stable and sustainable; and at the same time, it can intensify production causing less environmental harm, increase economic returns and support livelihood, and ensure food security (Barthelet al. 2013; Brookfield and Padoch 1994; Cromwell et al. 2001) It can help conserve soil, increase natural soil fertility and health, maximize the effective use of resources and reduce dependency on external inputs, and contribute to sound pest and disease management (Di Falco 2012; Thrupp 2000). In addition, it has also been increasingly evidenced that agricultural diversity reserves the potential to insulate the effects of climate change through adaptation and resilience (Kotschi 2006; Bellon 2008).

In the last two-three decades, there has been a plethora of studies reporting the general decline of agricultural biodiversity across the globe (Duvick 1984; Vellve 1993; Tripp 1996; Khoury et al. 2022; Fu 2006, 2015; Mir et al. 2012; Brush 1999; Brush et al. 1992; Hammer and Teklu 2008, but also see Montenegro de Wit 2016). A broad consensus is that the traditional landraces in the fields of farmers were largely replaced by modern or improved cultivars; so on-farm conservation of landraces has been greatly compromised (Brush et al. 1992; Hammer and Teklu 2008; Witcombe et al. 2011; Wood and Lenne 1997). There were macro-scale drivers at large including economic, agronomic, demographic, land-use, and other global environmental changes (Brookfield and Stocking 1999; Mwalukasa et al. 2002). Of all, one of the well-researched topics is the massive developmental program like the Green Revolution that geographically spanned three continents. It was actually implemented as a technological package to bolster the productivity of two staple cereals to render the country food secure. Though successful in raising the productivity of rice and wheat, it accelerated the erosion in cereal diversity, through the introduction and dissemination of modern varieties, the development and promotion of mega varieties, dismantling the agrarian systems, and forcing farmers to be dependent on external inputs and thus linking them to the market economy. However, the embryo of the Green Revolution that has assumed its demonic stature was implanted much before, perhaps with the emergence of plant breeding tools and technology, the creation of modern seeds, the growth of the seed sector, and the establishment of *ex situ* genebanks. The progress gained its inertia through rapid advancement in science and technology, especially crop improvement through plant breeding and global politics (Patel 2013). Concurrently, the political ecological context of their implementation has facilitated an irreversible and radical shift in agrarian activities. It, in turn, exerted its effect on agricultural biodiversity in many ways leading to its overall dwindling. However, the agrobiodiversity erosion at the country or continent level is far more recognized and well-described than its local dynamics. Specifically, how the larger global processes operated spatiotemporally at the local or regional level and caused gradual homogenization is inadequately understood.

Generally, the loss of diversity in cultivable forms usually measured in terms of certain markers (e.g., molecular markers) is often relatively discernable (Chakraborty and Ray 2019; Hammer et al. 2003; Ray et al. 2013). They offer insights into the loss in terms of the alleles, or other analogous measures of molecular diversity (Bayush and Berg 2007; Fu and Dong 2015; Fu and Somers 2009; Fu and Somers 2011; Martínez-Castillo et al. 2016; Martos et al. 2005; Van de Wouw et al. 2010a, b; Khoury et al. 2022). However, the ways of estimation of molecular diversity are often blind to the causal agencies, socio-cultural, economic, or demographic, underlying the loss of diversity. Therefore, the struggle to uncover the loss or change is often frustrated by limited information; for this reason, the investigation to unravel agrobiodiversity change turns out to be a simple exercise to estimate molecular diversity disabling to elucidate the big picture of change. Looking through the lens of Political ecology, the erosion of agrobiodiversity is not just situated within the domain of evolutionary biology or agricultural sciences but is perceived as rooted in historical and social processes (Blaikie 1985; Robbins 2019). It strives to untangle many ways in which political and economic interests shape agricultural development interventions. Therefore, political ecology tends to illuminate the larger picture operative against the backdrop of broad agrobiodiversity change. The changes that are not always directly detectable also capture key information, e.g., loss of acreage, introduction of modern cultivars, expansion of HYVs, extinction of certain landraces, etc. These also allow us to gain an indirect idea of the loss and drivers at large that are otherwise difficult to track down. Especially, the decline can occur in many different ways under the aegis of larger science and technological progress and intervention, developmental programs, socio-economic changes, cultural transition, etc., and analyzing the same is the main premise of the article. I would struggle to disentangle the various technological progress pertaining to breeding and improvement that led to agrobiodiversity erosion. In other words, by taking specific examples of crops, I would address the ‘how’ (did it happen) question. In doing so, a mixed approach will be employed and nearly all complementary measures detecting the change will be considered. For example, I gauge the introduction of modern varieties (the number of cultivars released in a period, etc), the replacement of traditional varieties or landraces, the increase in acreage under modern varieties or specific cultivars, the emergence of super- or mega-varieties, a specific program for crop improvement (for disease resistance or yield increment) and followed by the release of cultivars, monocropping and changing cropping pattern, and unusual rise in the acreage of certain crops at the cost of others (Brush et al. 1992; Hammer and Teklu 2008; Fu 2006, 2015; Fu and Dong 2015; Gao 2003). The idea is to capture the broad discernible changes in diversity and its socio-political or economic context of operation. Furthermore, I illustrate my points by dwelling on specific case studies on a variety of crops, rice, wheat, cotton, pearl millet, or pulses within the geography of India, however, some key crops will receive more focus than others owing to their status, importance to country's economy, data availability, etc.

5.2 The Global Agrarian Change

In traditional agroecosystems, genetically and phenotypically heterogeneous crop landraces have been cultivated in an assemblage of different crop species in a temporally and spatially diverse crop arrangement or cropping pattern; they are mostly managed with low externally procured inputs and family labor (Jarvis et al. 2008; Koohafkan and Altieri, 2011; Zeven 2002). This is in stark contrast with the vast swathes of modern crop fields performing monocultures of 'modern cultivars' developed through government- or private-funded projects and disseminated by private players or agricultural extension programs and supplemented with heavy inputs, i.e., agrochemicals, water, or power-driven machinery (Duvick 1984; Zhu et al. 2000). The imminent question arises: how did it happen? How was a majority of the traditional agroecosystems transformed into modern-day agricultural fields? The answer to the questions lies in the understanding of global agrarian change over the past two centuries. Furthermore, it has to be recognized that although the two extremes, traditional and modern, are broadly distinguished there exists a myriad of agroecosystems that fall in the continuum. In an increasingly globalized world, the divide between them has been blurred and in most cases, the traditional systems nowadays are intruded on by modern cultivars, energy-hungry irrigation systems, or external inputs. Generally, the diversity in traditional agroecosystems is managed through farmers' selection of random and novel mutations, their curation, and the cultivation of newer forms. It also encompasses various uncultivated edible or non-edible species and broader adjacent ecosystems. In traditional systems, the seed exchange often facilitates gene flow among landraces tapping and enhancing genetic variation, and continued cultivation and selection leading to local adaptation (Bellon 1996; Mercer and Perales 2010). Additionally, occasional introgression from crop wild relatives can also introduce novel variations (Jarvis and Hodgkin 2002). However, it will be untrue to say that traditional agroecosystems are completely geographically disjunct and farmers are averse to experimentation with newer varieties. On the contrary, they are keen to explore, innovate, and recurrently perform tests with newly arrived landraces to find out the suitability in their systems (Brush 2004; Chambers and Thrupp 1994; FAO 2014).

Historically, new crops and newer varieties were similarly traded, translocated, experimented with, and naturalized in the new geographic regions, sometimes across a larger continental distance, e.g., the great Columbian exchange was one of them but various crops were already traded and exchanged much before that, like the trans-Eurasian exchange of millets from Africa (Boivin et al. 2012), or African rice diffusion, etc. (Carney 2001). The cross-continental Silk routes were prominent land routes for quite a long time (Ray and Chakraborty 2021; Weatherford 2018; Spengler 2019). In a relatively recent period, for example, around the sixteenth or seventeenth century, enthusiasm to create newer varieties of vegetables or fruits was in full swing in Europe. Experiments were carried out, without knowing the underlying genetics, to produce vegetables or fruits of desired color, shape, or size (Kingsbury 2011). Another development in the agri-horticulture sector was also instrumental mostly in Europe. Until the seventeenth century, most seed saved by growers was sown in the following season with exchange and little trade. During the seventeenth and eighteenth centuries, a trade of seeds grew, particularly of fodder and 'garden' crops (i.e., vegetables), generally from the countries like Italy, France, and Switzerland to northern Europe. Other countries, Turkey and Syria, also contributed to this seed import (Kingsbury 2011).

Even though seeds of certain vegetables or fruits were packed and traded by some local producers in an organized manner, the scale of operation or the magnitude of the business was not big compared to today's scenario. The actual change began to happen after the development of modern cultivars through the technology of plant breeding and its sweeping entry into the agricultural sector. It brings us to the context of global agrarian change, and the transformation of traditionally managed agricultural systems in tandem. The science of plant breeding was spearheaded by the rediscovery of Mendel's laws of inheritance in the twentieth century which paved the path for the subsequent development of modern crop cultivars (Bateson 1904). It was a historic turn that not only allowed the scientists to exploit a new range of tools to investigate the biological world breaking into a smaller unit of the organization but also marked the beginning of the 'metamorphosis' of traditional agroecosystems. It enabled the material of regeneration, i.e., seeds, to be developed away from the agricultural fields by non-farmer scientists and subsequently distributed among the farmers. So, the technology of plant breeding has moved to research stations and performed by scientists, and gradually turned into a private-funded enterprise. As a consequence, not all crops were treated equally, and some became 'orphan crops', neglected by science, while economical crops won precedence (Ceccarelli 2009). The whole development thereby entirely reorganized the dimensions of the political ecology of agrarian activities (Clapp 2018; Howard 2015). Armed with the new technology, the plant breeders gradually garnered the power to exercise novel breeding methods to create newer types of agriculturally and economically important plants (Harwood 2016). There was a growing recognition of the value of landraces and their wild relatives (Zeven 1996, Zeven 1998) and the establishment of *ex situ* repositories or genebanks to preserve genetic materials for exploitation in breeding to create crops with desired traits like higher yield, greater pest and disease resistance, early maturity, greater biomass, etc. (Lehmann 1981; Saraiva 2013). It was set in motion by the global inertia to conserve diversity derived from landraces and crop wild relatives, away from fields, in the big genebanks (Fowler and Mooney 1991; Thrupp 2000). The initiative was accelerated by the alarms over the decline of crop diversity stemming from larger social, economic, or political changes (Harlan and Martini 1936; Samberg et al. 2013). So, the whole package of the technology of plant breeding, modern seeds, seed production laboratories, and *ex-situ* banks gradually began to operate to their capacity. It set loose the breeders to 'improve' crop species with their magic wand, thereby pitching an indomitable control over global agriculture through the formation of corporations (Clapp 2018; Hendrickson et al. 2017; Montenegro de Wit 2016). Some geopolitical regions were much ahead of others, especially the developed world from where the technology permeated to other regions. In the US, this was set in motion by the development of hybrid corn in 1930–40 (Kloppenburg 2005; Stone 2022). The socio-economic context to feed all was created by an urban population explosion that left no space for opening up new land for cultivation but to increase maize yield. The application of plant breeding techniques appeared to be a promising option (Duvick 2001). However, the concern over genetic erosion or loss of landraces surfaced with the mass propagation of plant breeding, at least in some parts of the world (Clapp 2018; Graddy 2013; Stone 2004).

In the late 1960s, the 'Green Revolution', a vehicle to lessen hunger in developing nations, foster economic growth, and secure political alliances, promoted new high-yielding cultivars and associated agronomic practices (Patel 2013; Ray 2022; Shah et al. 2021; Stone 2022; Subramanian 2015). It grossly accelerated the replacement of landraces and led to the destruction of the habitats of crop wild relatives (Pistorius 1997; Ray 2022). As a result, the notion of loss or genetic erosion received further attention, and the use of landraces was again felt to be essential in plant breeding (Frankel and Bennett 1970). Therefore, it remained at focus of any plant breeding or improvement program (Dwivedi et al. 2016). And, slowly, it opened the avenues to the formation and expansion of national and international institutions to collect, document, and maintain the genetic diversity of crops and their wild relatives in genebanks (Plucknett et al. 1987; Dempewolf et al. 2017; Fowler and Hodgkin 2004). The definition of agricultural diversity began to expand, recognize and include pollinators, landscapes, livestock, and non-crop species providing essential ecosystem services. It also embraced the significance of cultural diversity that has traditional agricultural knowledge at its core (Argumedo 2008; Koohafkan and Altieri 2011; Benz et al. 2000). The support for *in situ* or on-farm conservation gradually poured in to explore its role (Brush 2004; Brush and Meng 1998; Wood and Lenne 1997; Bellon 2004; Bellon 2008; Sthapit et al. 2001), though its efficacy was met with skepticism (Peres 2016).

Concomitant with the development was the rapid expansion of global seed industries and corporations that produced various agricultural inputs, mostly seeds and agrochemicals like fertilizers, pesticides, weedicides, etc. (Liu et al. 2015). The rise of industrial agriculture resulted in a fast increase in the use of inputs, mostly fertilizers, and pesticides, and thus the demand skyrocketed. In developing countries, it was promoted in the disguise of the Green Revolution (Ray and Chakraborty 2021; Ray 2022). On the one hand, the rise in pesticide use could be an outcome of the increased genetic homogeneity of crops nurtured in vast monocultures under intensified production systems (Altieri 2009); since genetic homogeneity tends to increase the vulnerability to pests or pathogens, which warrants chemical inputs to manage infestations (Andow 1983; Tilman 1999). On the other hand, the development of improved modern cultivars through breeding to take up fertilizers efficiently and produce the enhanced amount of grains rendered them dependent on mostly nitrogenous fertilizers, which led to a steady demand for fertilizers that went on rising ever since (Khush 2001; Liu et al. 2015; Heffer and Prud'homme 2016). And at the background, there were various mergers and mega-mergers of global corporations, a rise in their market share, and consolidation of their power to control world agriculture through the discovery and dissemination of technology in the form of seeds or chemicals, or mechanization (Clapp 2018; Clapp and Purugganan 2020; Hendrickson et al. 2017). However, the impacts of the broad changes at the global level on agricultural biodiversity may not be apparent but they continue to act towards homogenization through a multitude of proximal or distant drivers.

Responding to the rapid loss of the world's biological diversity, conservation, sustainable use, and equitable benefit sharing was prioritized through the Convention on Biological Diversity (CBD) in the 1990s (CBD 1992). After the CBD, the past agreements on the conservation of crop diversity were updated to accommodate the large framework, providing new avenues for collaboration through the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO 2002). In recent decades, the CBD, ITPGRFA, and Sustainable Development Goals (SDG) of the United Nations have formulated and mandated specific targets for safeguarding global agricultural diversity (CBD 2002, 2010; FAO 2002; United Nations 2015). It has been integrated into the major international agreements on biodiversity and human well-being and highlighted the importance and complementarity of both *ex situ* and *in situ* methods for crop genetic resource conservation (e.g. Ceccarelli 2009; Graddy 2013; Montenegro de Wit 2016; Samberg et al. 2013; Sthapit et al. 2001; Stenner et al. 2016).

5.3 The Indian Context of Agrarian Change and the Saga of Crop Improvement

The subcontinent could not feel the intense heat of the radical agrarian change taking place at the global level until the middle of the century. But, it does not imply that the attempts to improve the Indian agricultural systems were kept at bay, the colonial trials were already underway. In the late nineteenth century, repeated famines perhaps made the podium to reconsider the necessity of developing agricultural science in India. It further received a thrust by the Voelcker report which while praising the Government for irrigation facilities was critical of neglecting modern scientific approaches, especially manuring and yield increment (Arnold 2000; Voelcker 1983). But until the formation of the Indian Agricultural Research Station (later renamed Imperial Agricultural Research Institute), most of the initiatives remained in a rudimentary state. Moreover, the British mindset of pre-colonial Indian agriculture was based on the assumption that it was almost devoid of any meaningful scientific and technological tradition (Baber 1996). The repression of indigenous knowledge may not be because of their scientific faith or colonial bias, but to legitimize the affirmation of the state institutions and its agents (whether European or Indian) by the deskilling farmers (Preeti 2022).

To improve agricultural systems and increase productivity, an early attempt to introduce English wheat was criticized by Voelcker (1983). It was later substantiated by Albert Howard and Gabrielle Howard – the scientist duo who chose to examine the properties of three dozen different varieties of indigenous wheat. Subsequently, they developed rust-resistant hybrids that were well suited to the Indian conditions but superior in quality and market value to the existing crops (Arnold 2000). There was also the publication of the Royal Commission on Agriculture report which has been considered a major milestone in Indian agriculture as it objectivized seed sector development (Chauhan et al. 2017). Agricultural research in the country received further momentum from the Famine Enquiry Commission and Grow More Food Program Committee, which emphasized the need for quality seeds of improved varieties. Thereafter, many seed farms were established in community development blocks during the fifty's.

A major stride in agricultural research in India was pioneered by the inception of All India Coordinated Research Projects (AICRPs). The initial attempts to improve were made on maize in 1957 with the active collaboration of the Rockefeller Foundation and the first hybrid maize was released in 1961. Hybrid maize was followed by the release of the hybrids of sorghum and pearl-millet (Chauhan et al. 2017). Under the aegis of the program, the central research institutes, agricultural universities, and the State Departments of Agriculture were asked to work collaboratively to resolve the problems related to food security at the national level. Various coordinated programs on rice, wheat, maize, vegetables, fruits, and livestock were undertaken and have been executed in the last four-five decades (Chauhan et al. 2016a). Generally, the Indian programs, just like the global agricultural strategies, have been broadly aimed at the enhancement of yield, and improvement of other traits pertaining to adaptation, resistance to various biotic and abiotic stresses, and enhancing end-use qualities (Fu 2006, 2015; Mir et al. 2012). As a result, many modern varieties with higher yield (rice, wheat, pearl millet, cotton, etc), disease or pest resistance (e.g., various crops), short-duration (rice, wheat, pearl millet), or other desirable traits like specific staple length (e.g. cotton), cooking quality (wheat, rice), nutrient content (biofortified crops), or broader adaptability to grow in varied agro-ecological conditions (rice, wheat, maize, and many other crops) were released over the last decades (Anon 2017).

The application and wider dissemination of technology through the introduction, expansion, and establishment of modern cultivars are often flagged as harbingers of genetic erosion and homogenization (Fu 2006, 2015; Brush 1999; Hammer and Teklu 2008; Tripp 1996). They tend to have a long-standing and irreversible impact on agricultural biodiversity though this has not been systematically investigated in the Indian context or elsewhere. The improvement programs, for their highly specialized objective to enhance a narrow set of traits at a time, manipulate underlying gene(s), whereas the traits under improvement are often complex and polygenic, i.e., controlled by several genes (Heffner et al. 2009; Jansen 1996; Mitra 2001). In the process of developing new cultivars, they negatively influence the diversity of landraces or heirloom seeds that farmers have cultivated for various reasons, yield or disease resistance may not be the exclusive reasons. So, the entire exercise of valuing diversity, other than the desired ones, has been undermined. Although there has been a lot of concerns over the loss or decline globally, very little is known about the actual process operating on the ground. And, also not known is how its progress set in motion by the steps in the improvement programs which unequivocally replaced landraces with modern or improved or elite varieties in many different ways. Thus, I reiterate that I would address the 'how' (did it happen) question and develop my argument by citing examples of various crops and their trajectory of improvement over time.

5.3.1 Replacement of Traditional Varieties or Landraces – the Role of the Green Revolution

One of the better-known ways leading to the erosion of diversity is through the replacement of traditional varieties or landraces and the most well-documented case in India stems from rice. It is because rice being the primary cereal holds the highest stake in acreage and inevitably its history has been examined in greater detail. In the last seventy years, rice landraces have dwindled to a great extent. For example, an estimate says approximately 15,000 landraces of rice had been cultivated in undivided Bengal in the 1940s. The recorded number of landraces cultivated in West Bengal just before the 70s was little more than five and half thousand (Deb 2021). The Green Revolution and its extension activities have taken deep roots since 1970 and radically transformed Indian agriculture (Nelson et al. 2019; Shah et al. 2021). A few stout, short-stemmed, bushy semi-dwarf high-yielding varieties (HYVs) gradually substituted many traditional landraces of eastern, southeastern, and southern India at the outset. Later, many modern cultivars were developed responding to local agroecological requirements and it helped to expand the acreage under a few selected and successful HYVs (Pathak et al. 2019; Ray 2022). However, in the longer run , the spread and high acceptance of only a few modern HYVs like Swarna, MTU 1010, IR 36, Satabdi, etc further exacerbated the homogenization. Although the case of rice is more pronounced than any other crop many of the staples and non-staples experienced a similar loss of traditional varieties.

Wheat, India's second most important cereal, that has also been included in the Green Revolution package. The replacement of wheat landraces occurred almost the same way. Before the Green Revolution, most Indian varieties were tall with weak stems considered high in disease-susceptibility, high biological yield, low harvest index, longer vegetative and shorter reproductive period, and thus were not fit for intensive agriculture with external inputs (Joshi et al. 2007). To bolster wheat production, the semi-dwarf varieties were introduced from CIMMYT, Mexico (Kulshrestha and Jain 1982). It has been observed that by the late 1990s the semi-dwarf varieties covered over 80% of the wheat areas of all developing countries with adoption rates of 90% or more in South Asia (Byerlee and Moya 1993). From the beginning, many varieties adapted to different agroecological zones of India and neighboring countries (e.g., Nepal and Bangladesh) were released gradually (Evenson et al. 1999). They eventually succeeded in replacing numerous landraces cultivated in the wheat-growing zones of south Asia. Being major staple, wheat has been under a continuous process of varietal improvement. The developed varieties were one of the technologies that quickly diffused among the farmers during the Green Revolution period and later. Consequently, only a tiny area in the wheat-growing states of Haryana, Uttar Pradesh, Punjab, Bihar, Madhya Pradesh, and Rajasthan is currently under the traditional varieties or landraces. Broadly, such a trend is predictable as Haryana and Punjab have been the epicenters of the Green Revolution (Pavithra et al. 2017). Although the high-yielding semi-dwarf varieties under the flagship project of the Green Revolution worsened the process of decline, the erosion of landraces had begun quite earlier than that when crop breeding to develop modern varieties was underway in parts of India and the development of rust-resistant 'Pusa hybrids' were a few examples (Arnold 2000).

5.3.2 The Emergence of Hybrids

Successful production of crop hybrids and exploitation of hybrid vigor lay the foundations of a new era of plant breeding and crop improvement. Although the creation of hybrid rice for high-yield potential commenced quite later, a few other staples underwent the course of experimentation and led to the successful hybrid formation. In 1961, the first hybrid of maize or corn was released and it was soon accompanied by sorghum and pearl millet. Hybrid pearl millet was one of the first hybrid crops in the world and was released by the public sector institution in India in 1965. It was in contrast to the Green Revolution cultivars which were improved varieties of rice and wheat rather than hybrids.

Pearl millet or *bajra* is the third most widely cultivated staple crop after rice and wheat and has been grown on nearly nine million hectares. Being a cross-pollinated crop with high (approx. 85%) outcrossing rates pearl millet displays a high degree of heterosis for grain and stover yields (Burton 1983). The genetic improvement started in the 1930s to improve yield by mass selection and progeny testing, which led to the development of some open-pollinated varieties (OPVs). Since those OPVs were developed from a limited number of landraces, they provided minor improvements in actual yields. The major thrust for the development of OPVs began in the 1970s with the establishment of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The programs exploited a range of African germplasms and disseminated a diverse range of breeding materials. A diverse range of gene pools, populations, trait-based composites, and OPVs using germplasm originating in Africa and/or Asia was developed gradually till the late 1980s (Rai and Kumar 1994). The pearl millet hybrid era kicked off with the introduction of the male-sterile line, Tift 23A, into India from Georgia, USA in 1962. Five hybrids based on this line were released during 1965–69. The major thrust in pearl millet was to improve yield potential in fragile arid regions (Yadav and Rai 2013). After the release of the first pearl millet hybrid, the acreage under hybrids increased rapidly owing to higher yield. The spread of pearl millet single cross hybrids and their impact on production and productivity has been higher in regions equipped with better production environments. However, there has been limited adoption of hybrids in the arid zone due to their poor adaptation. Indian landraces were sources of early maturity, better tillering, and shorter height, whereas the landraces from Africa provided sources for larger head volume and seed size, higher degrees of resistance to diseases, and better seed quality. While the pre-hybrid era mostly relied on OPV and traditional varieties, the first hybrid era (1966–1980) witnessed the dominance of a few hybrids (17) and downy mildew disease was common. In the two subsequent phases from 1981, an increasingly large number of hybrids with genetically diverse parental lines was developed, and downy mildew was largely contained. It was followed by the use of highly diverse seed and pollinator parents and targeting broad niche adaptation (Yadav and Rai 2013). The high-yielding hybrids and OPVs have been widely adopted by Indian farmers and consequently, the area under improved cultivars has gradually increased over the years. Currently, a few improved OPVs and nearly eighty hybrids hold about 65% of the pearl millet acreage. Although the adoption of modern cultivars has been geographically patchy Haryana and Gujarat are the two top states in this regard (Yadav and Rai 2013).

Similar history of a widely grown pulse, pigeon pea, has been documented. Pigeon Pea is the second most important pulse in terms of acreage. The subcontinent is its center of domestication (Fuller 2011). The first variety of pigeon pea was developed by selection from a collection of wilt-resistant landraces (Shaw 1933, 1936). The scientific breeding effort progressed with the morphological and agronomic characterization of several elite pigeon pea field collections. It was followed by the identification of early and late maturing high-yielding types (Shaw 1933, 1936; Saxena 2008). Although the crop improvement activities by assessing field collections continued for nearly two decades they could not exert any significant impact on productivity. It began to gather motion with the All India Coordinated Pigeonpea Improvement Project in 1965 which applied the necessary impetus. Subsequently, nearly a hundred pure line varieties were released over the last 70 years resulting in substantial increases in production areas (Ryan 1997; Singh et al. 2005).

Between 1980 and 2000, various disease-resistant varieties were developed and the effort culminated in a number of hybrid development from the new millennium (e.g., ICP 8863, ICPL 87119, ICPL 332, ICPL 84031, ICPL 151, ICPL 88039, etc). For example, ICPL 87119 (Asha) is a wilt and sterility mosaic disease-resistant variety widely popular in the country and today occupies the largest area. So far, ICRISAT in active collaboration with various universities, institutes, and government bodies has released many hybrids (like ICPH 2671 and ICPH 2740). These hybrids have recorded a 30 to 40% yield advantage over farmers' varieties (Sameer Kumar et al. 2014). Although the specific cases of pigeon pea, pearl millet, hybrid rice, or cotton exemplify the integration of hybrids in agriculture, many more crops were brought under this technology in general and improved varieties diffused with varying success.

5.3.3 Introduction and Dominance of Mega-Varieties

Sometimes, the release of certain varieties developed through a long process of selection and breeding and disseminated across a large geographic region often marked a breakthrough in the history of crop science. The varieties subsequently received huge acceptance among farmers as well as consumers for higher yield, early maturation or multiple-disease resistance properties, better cooking qualities, etc. These mega-varieties still continue to be planted in a large acreage globally. Yet the examples from the other crops is less but the case has been well evidenced in the case of rice cultivar IR 36 or IR 64 (Mackill and Khush 2018).

International Rice Research Institute initiated the development of various improved cultivars through the rice crosses made at IRRI and they were assigned a number with IR (international rice) as a prefix. The first cross made in 1962 was named IR1 and the subsequent crosses were given consecutive numbers. IR8 was the variety developed in 1966 and was selected from the eighth cross made in 1962. Although known for very high grain yield IR8 had poor grain quality, lack of disease and insect resistance, and late maturity. Therefore, the attempts over the next two decades were made to develop varieties to improve greatly on these traits (Khush 1999). In early 1980, one of the most popular varieties grown was IR36 since it was resistant to disease and insects. Also, it demonstrated a higher yield within a shorter period of 111 days (from seed to seed) compared to IR8 (130 days) (Khush and Virk 2005). Eventually, it was fast accepted and was estimated to be planted on more than ten million hectare (ha) during the 1980s. While these early-generation IR varieties offered good productivity they still lacked the desired cooking quality (e.g., intermediate amylose content, gelatinization temperature, etc) of the pre-Green Revolution varieties grown in the Philippines and Indonesia. IR64, the coveted miracle rice, released in the Philippines in 1985, was a major breakthrough in combining the better palatability of cooked rice with a higher yield, disease resistance, etc. IR64 soon replaced IR36 in most growing areas and spread rapidly in newer areas. By 1995, IR64 has been successfully grown in eight million ha (Khush 1995). The wider acceptance and longer persistence of IR64 in farmers' fields were attributed to its excellent cooking quality (Champagne et al. 2010). Because of its relatively wide adaptation, early maturity, and improved quality, it gradually became popular and provided hundreds of millions of consumers with high-quality rice. Once, it was grown on 9–10 million ha annually (Laird and Kate 1999). Apart from the Philippines and Indonesia, it is also widely grown in India. During 1998–2006, IR64 alone accounted for over 10% of the breeder seed produced in India. It was still above 3% in 2015 meaning it was grown on 2–3 million ha annually. In the Philippines, the area of production of IR64 declined during 2000–2007 and was substituted by newer varieties, mainly due to its susceptibility to tungro disease. It has also given rise to the next-generation IR varieties. In India, the variety MTU 1010 became very popular, and it was derived from a cross between Krishnaveni and IR64 (Mackill and Khush 2018). Unlike the Philippines and Indonesia where the new varieties have replaced IR64, it is still popular in India. However, there are other mega varieties like *Swarna*, MTU 1010, and *Samba Mahsuri* that were released and spread across India. There were a few others that gained acceptance regionally (*Shatabdi, Khitish, Pankaj, etc*) over the large rice-cultivating zones (Ray 2022).

Although the term mega-variety has not been tagged to any specific wheat variety, two varieties, HD 2967 and PBW 343 have emerged as mega-varieties in terms of the large share of acreage in India. The wheat variety, HD 2967, released in the year 2011, emerged as the most popular accounting for 11% of the total gross wheat cultivated area in six states (Haryana, Uttar Pradesh Punjab, Bihar, Madhya Pradesh, and Rajasthan). Whereas the wheat variety, PBW 343, was also spread in all six states covering about 9.5% of the gross cropped area (Joshi et al. 2007; Pavithra et al. 2017). Large acreage held by mega-varieties of crops implied extreme monocultures of rice or wheat hinging on very few varieties. It eventually steers to gross genetic homogenization and the loss of diversity.

5.3.4 Not So Mega-Varieties but Few Popular Cultivars with a Large Share of Acreage

While very few mega-varieties like IR64 or HD2967 or their derivatives dominated the disproportionately huge chunks of agricultural fields of India or elsewhere for a period of time, there was another set of modern cultivars that also encompassed moderately large acreage. The large acreage held by a few varieties has been documented and evidenced in rice and wheat, perhaps owing to the wider success and acceptance of a small number of the Green Revolution varieties. Among the vegetable crops, the case of potato is well-documented.

In the past forty years, more than three hundred wheat varieties were released in India's six wheat-growing zones and this played a key role in increasing wheat productivity (Chatrath et al. 2006). It has been observed that although sixty cultivars have been cultivated in different zones, most acreage has been held by only a limited number of cultivars (Nagarajan 2005). For example, one of the widely-grown varieties, PBW 343, occupies around six million hectares (Joshi et al. 2007) whereas, in the North Eastern Plains Zone (NEPZ), HUW 234 has been the most abundant covering around 2–3 million hectares (Joshi et al. 2007). Similarly, in central India, an old variety, LOK 1 (released in the year 1982) is the most cultivated variety (Anonymous 2003). Echoing a similar pattern, a study to evaluate the spatiotemporal spread of modern wheat cultivars in the top five wheat-growing states of India (Haryana, Uttar Pradesh, Punjab, Bihar, Madhya Pradesh, and Rajasthan) found that the large acreage held by only a small number of varieties, HD 2967, PBW 343, PBW 550, Lok 1, PBW 502. Of these, HD 2967 and PBW 343 are the top two wheat cultivars and covered 11% and 9.5% of the area share in 2013–14 (Pavithra et al. 2017). When wheat acreage under modern cultivars is broken down state-wise, we obtain further insights into the extent of concentration of the top varieties in five states. The gross wheat area of a state covered by the top five cultivars varied widely from 88.7% in Punjab to 42.9% in Uttar Pradesh. More or less 80% area is held by only five cultivars in Haryana (79.05%), Bihar (80.75%), and Punjab (88.66%) which portrays an acute case of genetic homogenization. Even in the states with the least acreage by modern cultivars, Uttar Pradesh, Madhya Pradesh, and Rajasthan, the percentage is no less in magnitude (42.9–60.9)%. A few of the cultivars, e.g., HD 2967, the most popular in Punjab, covered about 57% of the acreage while it occupied 14.5% in Haryana. Single variety occupying a large area has been reported earlier; C5912, in 1955, occupied nearly 80% of the wheat area in Punjab (Pal 1966). Similarly, another popular variety, PBW 343, in Bihar, Haryana, and Uttar Pradesh encompassed 30%, 20.2%, and 14.7%, respectively (Pavithra et al. 2017).

The story of rice following the Green Revolution reiterates the same trend. The early phase of the Green Revolution began in 1964 when Taichung Native 1 (TN-1) was imported to India. Later, several other HYVs (*Akashi, Bala, Cauvery, IR20, Jagannath, Jamuna, Jaya, Krishna, Pankaj, Prakash, Ratna, Sabarmati, Sona*) were experimented with till 1982–83 and the area under HYV in India grew steadily from a minuscule of 2.5% in 1966–67 to almost fifty percent in 1982–83 (Dalrymple 1986). However, the success of an HYV and its acceptance differed widely among the cultural geographic regions. For example, in West Bengal and a few other adjoining states, around 25–30 high-yielding rice varieties, e.g., *Shatabdi, Khitish, Gotra Bidhan* 1, IR 36, IR 64, *Lalat, Ratna,* MTU 1010, etc. were popularly grown during *boro* season under completely irrigated conditions. Of which, *Shatabdi* (11%)*, Khitish* (6%)*,* IR 36 (6%), MTU 1010 (6%), *Lalat* dominated the *boro* cultivation all over the state (Adhikari et al. 2011; Pandey et al. 2015). Similarly in *aman* season, out of sixty HYVs a few like *Swarna, Pankaj, Ranjit, Sashi, Samba Mahsuri, Mahsuri, Sabita, Hanseshwari,* etc. covered more than half of the total cultivated area. *Swarna* alone encompassed 43% of the area (Pandey et al. 2015). It implied a serious narrowing of the genetic base of rice since most of them are genealogically derivatives of either TN1 (a semi-dwarf variety from dwarf *Chow-wu-gen* and *Tsai-Yuan-Chunj*) or IR8 (a cross between high-yielding *Peta* and Taiwanese dwarf variety *Dee-geo-woo-gen*) (Pande and Seetharaman 1980) and more or less genetically homogenous. Further acceptance of even fewer HYVs based on their actual performance in the field resulted in an extreme narrowing of diversity. Although newer cultivars were developed in the succeeding decades diversifying the parental gene pool (Pingali 2017), *Swarna* and a few others still overwhelm the eastern Indian rice fields.

The story of potato cultivation also portrays the same trend (Pradel et al. 2019; Gatto et al. 2018). Only three cultivars, Kufri Pukhraj (released in 1998), Kufri Jyoti (released in 1968), and Kufri Bahar (released in 1980), covering 71% of the country's potato growing area is shared by Assam, Bihar, Madhya Pradesh, Punjab, Gujarat, Uttar Pradesh, and West Bengal. Kufri Pukhraj, a high-yielding and early-maturing variety, has been the most common variety covering 33% of the total potato area in 2015. It is the most abundant variety in Punjab, Gujarat, and Bihar and the second most abundant in Uttar Pradesh and West Bengal. Kufri Jyoti stands second in potato acreage (21% of the area) in 2015. It has been the dominant variety in Karnataka and West Bengal in 2015 and the second most important in Punjab. It is still preferred for good storability, tuber size, and a slow degeneration rate despite increasing susceptibility to late blight and lower yield compared to Kufri Pukhraj (Kumar et al., 2014). Kufri Bahar is the third most common potato cultivar which covers 17% of the potato area. It is the most popular in Uttar Pradesh but it is susceptible to late blight and produces moderate yield. Alongside survives *Bhura Aloo*, a native variety, particularly in Bihar. It has been cultivated for its red skin regardless of low productivity and late blight susceptibility since farmers prefer red-skinned potatoes for their higher market value, just like Kufri Sindhuri and Lal Gulal.

Replacement or the crowding-out effect is a common phenomenon that has been documented in many other crops. In this realm, other 'not-so-superior' varieties are eventually substituted by the choice driven by the acceptance of superior varieties. The superior variety could be a variety of the crop that fetches a premium price, is exportable, has better acceptance in terms of taste, etc. There are many examples, the replacement of a wide diversity of quinoa landraces in Bolivia with the internationally popular white and red types (Bioversity International 2013; Drucker et al. 2013). A near similar case was observed in several basmati landraces with different sizes that have been cultivated for generations. Owing to the narrow size specification of basmati for geographic indicator tag, thereby facilitating export has had an unintended impact on the local diversity of basmati landraces that once existed in the core cultivation zones (Osterhoudt et al. 2020). Another example can be sought from mango, the replacement of a wide range of old mango varieties with the popular and geographic indication-protected variety *Dashehari* has occurred in Uttar Pradesh (Rajan et al. 2016).

5.3.5 Changing Cropping Pattern

The decline of autumn rice, known variously as *aus, ahu*, or *bhadai*, illustrates an example of how the introduction and adoption of the Green Revolution HYV can change the cropping pattern and lead to a near-loss of a group of indigenous rice.

Pre-monsoonal upland rice or autumn rice has been cultivated in the relatively higher lands of the Indian subcontinent for centuries (Ray and Ray 2018; Chakraborty and Ray 2019; Ray In Press-a, 2023, 2022). It was an upland crop generally cultivated with relatively little water and generally broadcast in the drier months of March or April when occasional mild rains used to moisten the soil. It used to survive under mild water-limiting conditions of May. In the early monsoon in June, it matures followed by harvest in autumn between July and September (Ray In Press-a, 2023, 2022). This moderate-yielding rice was grown on relatively higher lands where cultivation of the rainfed transplanted *aman* has not been possible. Extended Bengal (that included Assam, Orissa, Bihar, and modern-day Bangladesh) has had a rich tradition of autumn rice cultivation (Allen 1905; Hunter 1876a, b; Vas 1911; Marshall 2006). It remained the second most important rice crop, next to *aman* or monsoonal rice, in Bengal and the eastern part of India. However, with the firm establishment of HYVs, especially the rising popularity of *boro* or summer rice, a gradual disappearance of *aus* or autumn rice has been observed. Many *aus*-growing districts with no to little *boro* acreage in 1946–47 switched to nearly 40% of their rice acreage to *boro* cultivation in 2014–15. In West Bengal, the *aus* acreage has shrunk to almost half whereas *boro* skyrocketed over a period of seventy years (from 10.2 thousand hectares in 1946–47 to 1271.72 thousand hectares in 2019–20) (Ray 2022). Neighboring Bangladesh has also demonstrated a similar phenomenon of technology adoption, from 1969–71 to 2006–08, the area under *aus* cultivation contracted from 3.24 to 0.96 million hectares and *boro* rice increased from 0.89 to 4.4 million hectares (Hossain 2010; Biswas 2017). The change in cropping patterns ignored the underlying agroecology of rice cultivation. In the past, *boro* was grown in winter in low-lying flood-prone areas after flood water receded. But the combined package of new HYV seeds, fertilizers, and groundwater has ensured its higher productivity; it offered a higher dividend that helped *boro* (or the Green Revolution in eastern India in general) to gain acceptance and eventually lead to the decline of *aus* diversity. It also brought in other changes alongside. Rice-wheat cropping system promoted through the Green Revolution also caused the shrinkage of coarse cereals, pulses, oilseeds, fruits, and vegetables in some states of the Indo-Gangetic plains and around (Ray et al. 2021; Singh 2000), though the magnitude of this change or its impact on diversity has not been well-examined.

5.3.6 Promotion of Cultivars with Specific Qualities

In some cases, the demand for specific characteristics of crops encouraged some cultivars to win farmers' choice, e.g., cotton cultivation in the subcontinent. It illustrates a case of how the historical trajectory of cash crop cultivation has undulated with the state apparatus, trade, taxation, policies, and technology diffusion (Flachs 2019; Menon and Uzramma 2017; Stone 2007, 2011). Two indigenous species were domesticated (*Gossypium arboreum*) or naturalized (*G. herbaceum*) in the subcontinent and profusely cultivated for thousands of years (Menon and Uzramma 2017;

Wendel et al. 1989). They produced elegant fiber of short-staple length that was fed to the local weaving facility for making the desired textiles. The industrial suitability of long-staples had facilitated the acceptance of exotic species followed by the gradual alienation of indigenous species. The seed of decline germinated a couple of centuries ago but the last sixty-seventy years experienced an intense wave of change. The erosion commenced in the early phases of tetraploid cotton introduction, expansion, and subsequent patchy cultivation in the eighteenth and nineteenth centuries. It amplified with the advent of the twentieth century through the introduction of hybrid cotton followed by Bt cotton hybrids and continued at an undiminished pace. Therefore, the long process of genetic erosion in cotton seems to be well rooted in history and multi-phased in its development.

In the early phase, two tetraploid species (*Gossypium barbadense, G. hirsutum*) were introduced in the late seventeenth century. At the outset, the two species were restricted and acreage was minuscule compared to the indigenous species until the early twentieth century. Despite vulnerability to pests, extreme heat, etc., the trials were in full swing owing to long-staple length. The socio-political changes taking place in the subcontinent greatly affected desi cotton; for example, industrial ginning was rapidly replacing hand ginning and their demand for long-staple varieties suited to the new machine was rising. Most of the indigenous varieties were of shorter-staple length and were unfit for ginning in industrial looms. Additionally, the discriminatory taxation and other policies imposed by the then ruling British administration discouraged Indian textile production (Menon and Uzramma 2017). Consequently, the acceptance of introduced species gained as the demand for a longer staple continued to surge. In the intermediate phase (1900–1970), acreage began to rise from the early twentieth century and it gathered momentum after the middle of twentieth century. By 1946–47, *G. hirsutum* was, however, only restricted to 3% of acreage while *G. arboreum* and *G. herbaceum* occupied 65% and 32%, respectively (Boopathi and Hoffmann 2016). Between 1970–71 and 2013–14, the acreage of *G. hirsutum* soared gradually to 42% and 91%, respectively. It was likely that the increment in acreage gained its inertia from the establishment of the Central Institute of Cotton Research and a country-wide improvement program in the early twentieth century. In tandem, the episode of the decline of cotton landraces continued. In the penultimate phase, after the introduction of the first *hirsutum* x *hirsutum* hybrid in 1970, the area under indigenous species continued to shrink rapidly. It followed the release of various intra- and interspecific hybrids for commercial cultivation (Singh and Kairon 2001). Moreover, the objective was to generate and release higher-yielding, improved fiber (long and superior-medium staple length), and short-duration varieties. The proclaimed 'high-quality' and homogenous new cultivars raised through breeding widely spread and further marginalized the use of indigenous cotton. As a result, *G. arboreum* and *G. herbaceum* retained the shares of 17% and 13% of the acreage in 1989–90. Also, the varieties of *G. barbadense* were reduced to a mere 0.3% of the acreage (Boopathi and Hoffmann 2016). Essentially, the outcome was mostly high-yield varieties of *G. hirsutum* grown in input-intensive monocultures. The final phase earmarked the introduction of Bt-cotton, a genetically modified variety developed from *G. hirsutum* hybrids, in

2002. The situation worsened further (Gutierrez 2018; Gutierrez et al. 2015). It was adopted by cotton farmers and is grown in nearly 90% of Indian cotton fields nowadays. The genetic constitution of cotton today in India comprises *G. hirsutum* (*hirsutum x hirsutum* Bt cotton hybrids) and it is represented by a few commercial varieties with a specific and narrow range of fiber, i.e., superior medium and long-staple. Moreover, Bt hybrids swept out many popular cotton varieties, AKA 7, AKA 8, GCot 11, GCot 13, LRK 516, MCU 5, SVPR 2, PA 225, RG 8, Sahana, and Surabhi, etc. which were once cultivated even in the marginal conditions. The production of extra-long-staple has also dwindled largely due to the replacement with superior-medium and long-staple cultivars. The acreage under *hirsutum x barbadense* Bt-hybrids remained tiny compared to *hirsutum x hirsutum* Bt-hybrids (Boopathi and Hoffmann 2016). As a result, the widespread adoption of Bt cotton has led to a recent bottleneck and extreme narrowing of the cotton genetic base.

5.4 Unwarranted Impacts of Biofortified Crops on Agrobiodiversity

The development, dissemination, and acceptance of crop cultivars with specific qualities like higher yield, disease or pest resistance, short maturation time, better storability, etc. have had a long-standing consequence on crop diversity. This has been clearly demonstrated by hybrid and Bt cotton. The recent phenomenon of biofortification or the production of nutrient-enriched crops also falls in this line. Biofortification is the process of increasing the density of micronutrients in widely-consumed crops either through traditional plant breeding, agronomic practices, or genetic modification (Bouis and Saltzman 2017). It aims to increase crops' content of iron, zinc, vitamin A or other micronutrients to improve nutrition and health; more specifically, these crops are claimed to mitigate hidden hunger that has been plaguing millions of people around the world now (Potrykus 2010). The meticulous attempts by Indian scientists to develop biofortified crop cultivars are not lagging behind.

Indian Council of Agricultural Research (ICAR) has embarked on improving the nutritional quality of high-yielding varieties of cereals, pulses, oilseeds, vegetables as well as fruits using breeding methods. During the 12th Plan, a special project on the Consortium Research Platform on Biofortification has been launched. The concerted efforts from the collaboration with other national and international initiatives have led to the development of 71 varieties of key crops. Among them are multiple varieties (more than three) of rice, wheat, maize, pearl millet, finger millet, mustard, and soybean. In addition, one variety of linseed, cauliflower, pomegranate, and more than one variety of lentils, groundnut, potato, sweet potato, and greater yam have been developed. A large number of elite materials are awaited to be released over the years and special efforts have been channelized to popularize them among the common people. The mega-project claimed to assume great significance to achieve the nutritional security of the country (PTI 2021). Quality seeds were produced and disseminated for commercial cultivation. The Extension Division of ICAR has been instrumental in launching two special programs, e.g., Nutri-sensitive Agricultural Resources and Innovations (NARI) and Value Addition and Technology Incubation Centres in Agriculture (VATICA) to upscale these varieties through various Krishi Vigyan Kendras (KVKs) (Yadava et al. 2020). Although genetically modified organisms have not yet been introduced through biofortified crops into India, GM rice or vitamin A-enriched golden rice cultivation has started in the Philippines, and Bangladesh is perhaps following in the footsteps (Ahmad 2022).

A seemingly humanitarian 'science for social welfare' project to end the world malnutrition problem can give rise to many detrimental effects on the social, economic, and cultural lives of the people (Ray 2021; Ray and Ray 2022). The putative impact on agrobiodiversity cannot be ignored. Many commentators have hypothesized the process of genetic erosion will inevitably be exacerbated by the introduction of such varieties in many different ways (GRAIN 2019; Ray 2021; Ray and Ray 2022). They argued that the cultivation of biofortified crops would encourage monoculture instead of diversified cropping systems. Importantly, the impacts of biofortified crops on indigenous biodiversity can be severe since the targeted regions of Asia, Africa, and South America are the centers of diversity or secondary centers of domestication of many crops. Earlier, a significant portion of diversity has been lost through HYV crops promoted via the Green Revolution. A similar process might work in the case of these crop cultivars. The special traits of these 'high-value' varieties might help them win farmers' choices driven by the market. It could happen through the higher demand created and elevated among the public for a particular 'high-value' variety; consequently, the farmers might be rewarded by growing the cultivars that would fetch an ensured better price and eventually will slowly shift to cultivating these cultivars only. There are worrying cases of promoting biofortified crops disregarding the diversity of nutritious and resilient local cereals and vegetables. The varieties also tend to disrupt local networks to restore underutilized or orphan crops (GRAIN 2019). Closely linked with the indigenous crop diversity is the case of seeds and food sovereignty that might be imperiled by the mass adoption of biofortified crops (Garcia-Casal et al. 2017). Whereas enormous edible floral diversity have been regarded as a reservoir of micronutrients that may hold the potential to reverse problems of hidden hunger (Cantwell-Jones et al. 2022; Ray et al. 2020; Ray and Ray 2022).

5.5 Drivers of Change in Agrobiodiversity: Yield Enhancement and Others

Intensification of production has not only been a demand of the nineteenth or twentieth century, but it gained its pace earlier in history when peasants intended to enhance their production, by choosing better-suited varieties, increasing cropping intensity, making judicious use of monsoonal rain, provisioning irrigation facilities, proper manuring, and exploiting certain fertile landscapes (e.g., river banks, flood-beds) (Fisher 2018; Habib 1963). The state intervened in these activities by providing corpus funding or channelizing the labor force for major irrigation canals, dams, digging water tanks adjoining temple-linked lands, irrigation channels, exploiting nearby temporary wetlands, and inundation from the seasonal floods (Krishna and Morrison 2009; Morrison, 2019). All of which, together or in isolation, facilitated intensified production of crops, that perhaps varied in success; some geographic regions were well-off enough to offer more than others (Fisher 2018; Ray In Press-a; Habib 1963). In other words, intensification was not possible everywhere but in certain geographies endowed with fertile soil, rainfall or irrigation facility, available labor force, etc. Also, with the increasing urbanization more land was brought under cultivation, by deforestation, reducing fallow, turning pasture, or grazing land into use that either enabled higher production or moderate production with less labor and money through extensification (Parthasarathi 2001; Ray In Press-a). In tandem with the growing food demand or increased taxation, fertile lands were cultivated twice or even thrice per year, i.e., higher production was achieved not only through increased yield or productivity from the same land but also by increased cropping intensity, e.g., double or triple cropping instead of single cropping (Fisher 2018). So, the trend to obtain more from the same piece of land has driven the peasants since the historical period and the saga continued responding to various social or economic stimuli.

However, the spatial scale and magnitude of intensified production have not been so wide and high prior to the modern-day crop improvement programs that explicitly hinged on the objective to boost crop yield. As economists argued that the agricultural output (all crops together) grew at a rate of around 3.2% per annum during the period 1949–50 to 1977–78. When decomposed, the growth rate of food grains and non-food crops was 3.19% and 3.22% per annum, respectively (Srinivasan 1979). These numbers are several times higher than 0.37%, 0.11%, and 1.31% per annum growth rates respectively for all crops, foodgrains, and non-food crops during the period 1892–1947 in then British India (Blynn 1961). In the following years, during the 1980s and early 1990s, agricultural growth was significant as evidenced by the performance of the crops, livestock, and fisheries sectors. The crop sector showed modest but still substantial growth during the early 1990s (Singh and Pal 2010).

Although it cannot be denied that various crop traits, viral, bacterial, or fungal diseases (smut, rust, blight, etc.) or pest (plant hoppers, mealybugs, borers, bollworms, etc.) resistance, early maturation, wider adaptability, better eating and cooking quality, were the key factors that have largely shaped the aims of the improvement programs, the enhancement of yield has always been the primary focus. At the country level, all cumulatively contributed to intensified production as India had a little extra land to be cleared for agriculture after 1960, the Green Revolution episode. Before that, agricultural expansion at the expense of forests was the key contributor to landuse landcover change and the process continued until the 1960s (Roy et al. 2015). The spurt in yield has reached a great magnitude in the last fifty-sixty

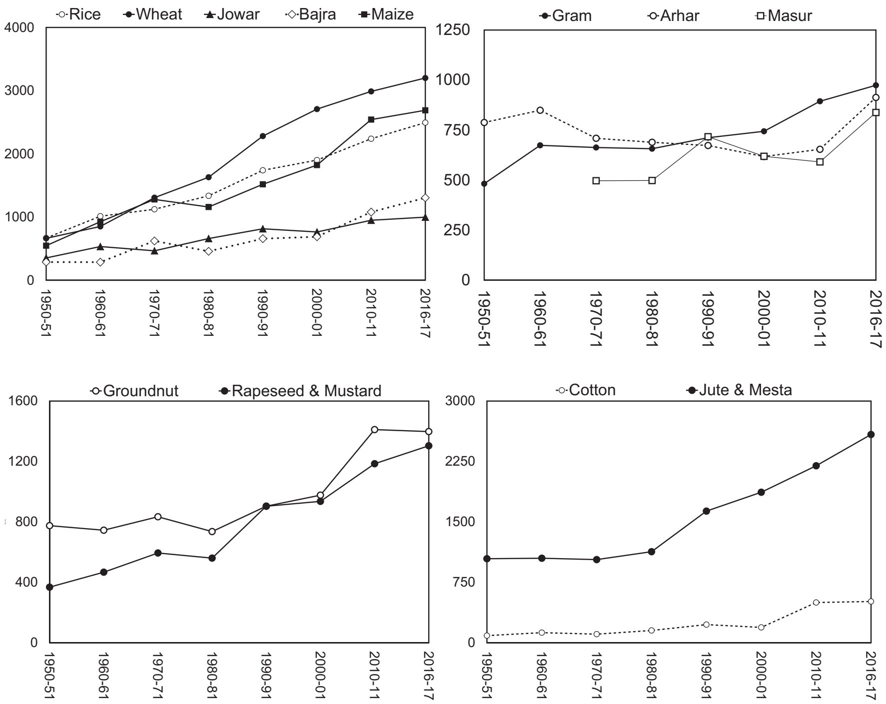

Fig. 5.1 The increment in yield (kg/hectare) of major food and fibre crops in the last sixty-seventy years period [Source: Directorate of Economics & Statistics, DAC&FW, Govt. of India]

years, be it staple cereals, pulses, oilseeds, or fibers (Fig. 5.1). The application of improved modern cultivars developed through breeding or genetic engineering supported by the provisioning of irrigation, especially in the form of groundwater (Fig. 5.2), easier access to fertilizers (Fig. 5.3), assured market, cheap labor, etc. catalyzed the gradual process of rising productivity. And, the enhanced productivity culminated in a huge rise in production (Fig. 5.4).

So, can we find a causal link between crop improvement programs and dwindling agrobiodiversity? Can we trace back the huge rise in productivity to a limited number of modern cultivars? And does that not translate to the process of abandonment of heirloom seeds or landraces and eventually to genetic diversity erosion? The response is likely to be positive; we can find a set of probable drivers at large. The massive improvement programs, mediated through the influence of science and technological advancement and application undertaken over a large spatiotemporal scale, led to an intensified production. Dabbling with and accelerating the yield factor has been the prime mover in addition to other crucial objectives. So, the steady intensification of production happened over the period of sixty to seventy years mostly driven by the yield increment. It also seemed to be reliant on a few sets of elements in a package, i.e., improved seeds, enhanced fertilizer or pesticide applications, elevated use of groundwater, extension support, etc. that were intricately linked and underlying drivers of agrobiodiversity depletion.

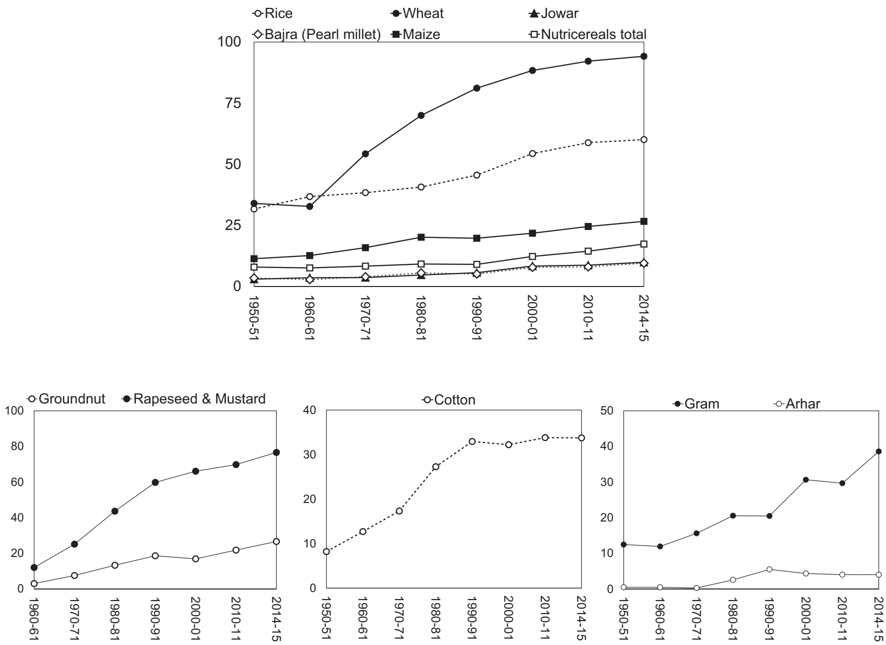

Fig. 5.2 The increment in acreage under irrigation facility (as a percentage of total acreage) of major food and fibre crops in the last sixty-seventy years period [Source: Directorate of Economics & Statistics, DAC&FW, Govt. of India]

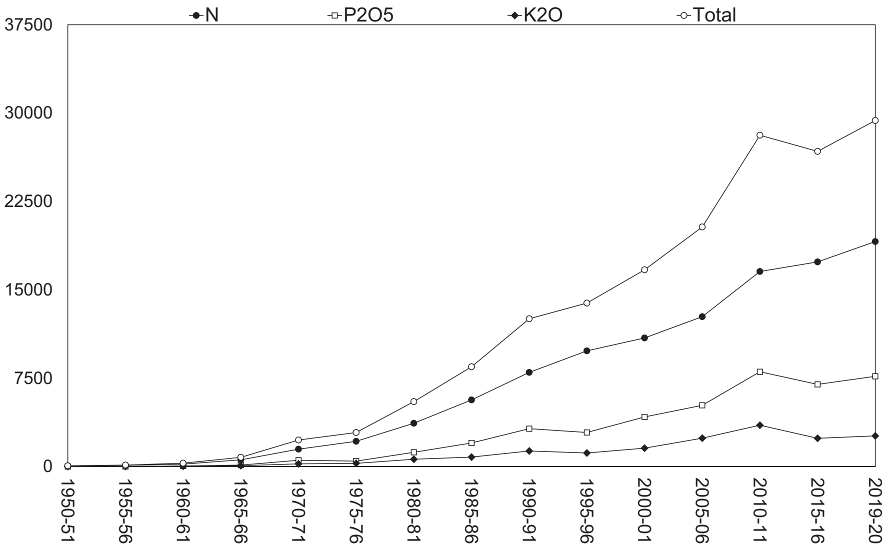

Fig. 5.3 The increment in total fertilizer consumption (Nitrogen (N), Phosphorous (P), and Potassium (K), and total NPK) (in thousand tonnes) in the last sixty-seventy years period [Source: Directorate of Economics & Statistics, DAC&FW, Govt. of India]

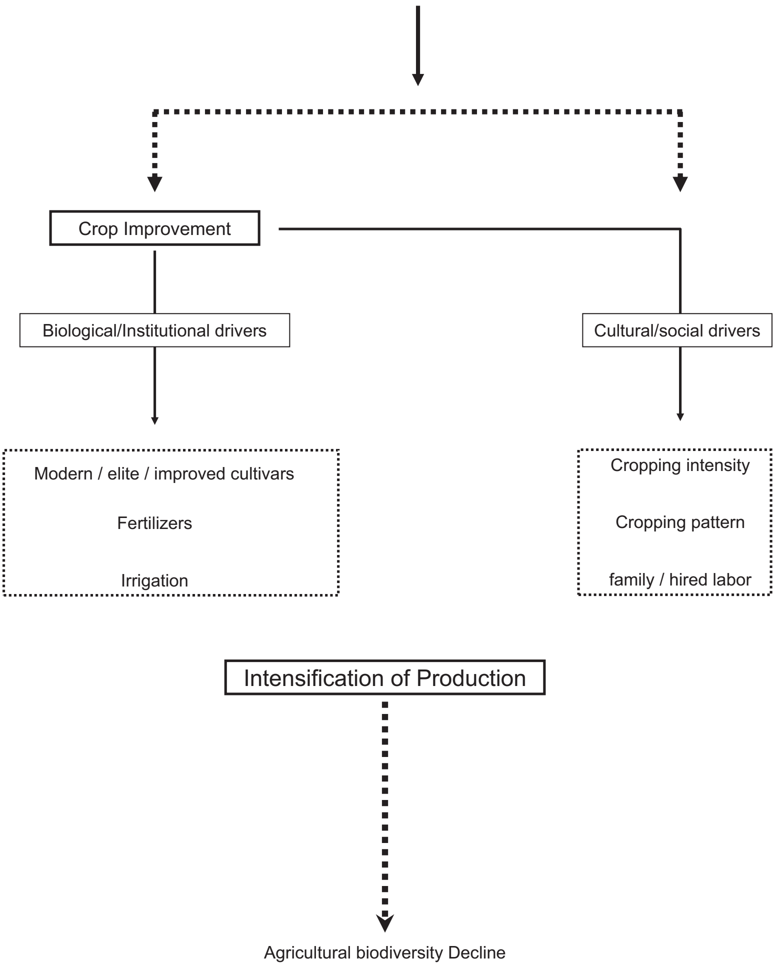

Fig. 5.4 The network of underlying drivers of agrobiodiversity decline

5.6 Implications for Food Security

Science and technological progress have ushered great hope in raising productivity, containing few diseases or pests, customizing crops for specific qualities, enhancing abiotic stress tolerance, or shortening maturation time to enhance production. Seemingly, it allowed farmers to reap a better harvest and the country to reach a state of food security. However, among several well-documented fallouts, the spatio-temporal decline of agricultural biodiversity and its impact on various social, economic, and cultural fronts has been quite evident. Here, I summarize the key effects of the decline of diversity that underlie the larger development program.

5.6.1 Disease /Pest Susceptibility

The decline in agricultural biodiversity can be gauged as follows: of approximately 250,000 plant species about 50,000 are edible. We actually consume no more than 250, out of which fifteen crops give 90% of the calories in the human diet, and three of them, namely wheat, rice and maize provide 60%. In these three crops, modern plant breeding has been particularly successful, and the process towards genetic uniformity has been rapid – the most widely grown varieties of these three crops are closely related and are more or less genetically uniform (pure lines in wheat and rice and hybrids in maize). The major consequence is that our main sources of food are more genetically vulnerable than ever before, i.e. food security is potentially in danger (Ceccarelli 2009).

The major biological effect of crop improvement is the reduction of diversity, phenotypic and genetic (Fu 2006, 2015; Louwaars 2018) which has a long-standing effect on the adaptive evolution of the organisms. In the distant past, crop plants founded by small population(s) have undergone genetic bottleneck(s) while domestication, either single or multiple times in geographically disjunct locations (Doebley et al. 2006). While it has caused a drastic reduction of diversity from their wild ancestors due to the bottleneck, ancient farmers were able to unleash and tap diversity through artificial selection of favored mutation, curation, maintenance, and enhancement; and it occurred over large geographic regions over several thousand years that facilitated modern crop species to accumulate genetic and phenotypic diversity (Hufford et al. 2019). Geneflow from wild ancestors or semi-domesticates, hybridization and random mutation are used to operate in unison to create this pool (Cornille et al. 2014; Meyer and Purugganan 2013). The outcome was enormous diversity of domesticated, semi-domesticated, and naturalized edible species manifested in thousands of local landraces (Dwivedi et al. 2016; Ray et al. 2013). However, the modern-day improvement phase was another such bottleneck that crop plants encountered and it has also resulted in the decline of diversity since even a smaller subset of selected individuals was chosen for further experimentation (Van de Wouw et al. 2010a, b). Also, plant breeding technology attempted to combine as many ‘favorable traits’ as possible in one genotype or maximize the presence of such traits in one population. Therefore, diversity in the variety or within populations is further reduced. Moreover, it preferred pure-line selection instead of multiline as in landraces or traditional varieties. The net effect is nurturing uniformity in the field (Louwaars 2018; Fu 2006, 2015).

So, the reduced diversity in crop plants compared to their wild ancestors is common, but the magnitude of the diversity loss in plant breeding or improvement programs is alarming in terms of sustaining agriculture, combating disease or pests, adapting to climate change, mitigating crop loss, and ensuring food security (Fu 2006, 2015, 2017). As discussed in the last few sections, the reduction of diversity is sometimes so acute that only a few desired cultivars dominate agricultural fields. The effect of narrowing of diversity is quite severe in evolutionary terms, it robs the organism of the power to adapt to any change in its environment, be it a change in climate, a disease, or pest outbreaks (Edwards 1996). There are many examples from the past or relatively recent times when a narrow genetic diversity of crop plants in monocultures caused disease emergence or recurrence, crop loss, or famine in extreme cases (Thrupp 2000, 2003; Pring and Lonsdale 1989). On many occasions, it could be difficult to identify the actual causation of such events, as many players loom large and co-contribute to the disease outbreak, e.g., the repeated infestation of cotton plants by cotton bollworms, the emergence of resistant bollworms can be cited to substantiate the claim that low genetic diversity could be one of the factors along with many other socio-economic or cultural variables. Sometimes, secondary or minor pests reincarnate into major pests owing to a change in the microenvironment and susceptibility of the improved ones, e.g., brown plant hopper in high-yielding rice cultivars (Ray 2022). Taken together, it hints at greater risk and vulnerability to various biotic and abiotic stresses, let alone climate change.

5.6.2 Gradual and Inevitable Changes in Food and Nutrition

The causal link between crop improvement and its detrimental effect on food and nutrition is not generally spoken aloud but the reverse is mostly cited as the benefactors. The modern cultivars are often portrayed as a silver bullet to fight hunger and malnutrition through the overtly simple narrative of customized genetic manipulation, overproduction, and lowered food prices (Bouis and Saltzman 2017; Khush 2001). However, when analyzed closely a distant but clear link can be perceived, at least in selected cases. The context and the causal factors are somewhat comparable to the intermediate or inclusive factors that have been proposed to study the links between malnutrition and crop improvement by Ferguson et al. (1990).

I briefly argue on this aspect drawing on two main staples, rice and wheat. It has been observed that the overwhelming diffusion and acceptance of modern high-yielding cultivars of rice and wheat has cascading effects on various fronts pertaining to food and nutrition through the complex and interrelated chain of factors. Although it operated distantly and indirectly through various pathways involving a number of intermediate factors it finally resulted in food or nutrition insecurity. Divergent agrarian activities and associated cultural practices have been molded and reshaped by the production of high-yielding varieties of rice and wheat. For example, through monocropping, changed cropping patterns, high-input demanding systems, overproduction of staples, and subsequent feeding of the same product to the public distribution system, the rice-wheat cropping systems employing HYVs eventually modified the food systems of many regions of the country (Ray et al. 2021) (Fig. 5.5). Increased acreage of rice and wheat acted in some ways to discourage the cultivation of pulses, fruits and vegetables, and coarse cereals. The staples were further channelized into social welfare programs like public distribution systems that essentially relied on mostly rice and wheat which made their access easier in various parts of the country. All of these, cumulatively, tend to have an impact on the food and nutritional outcome of a large section of society (Singh 2000; Kataki 2002).

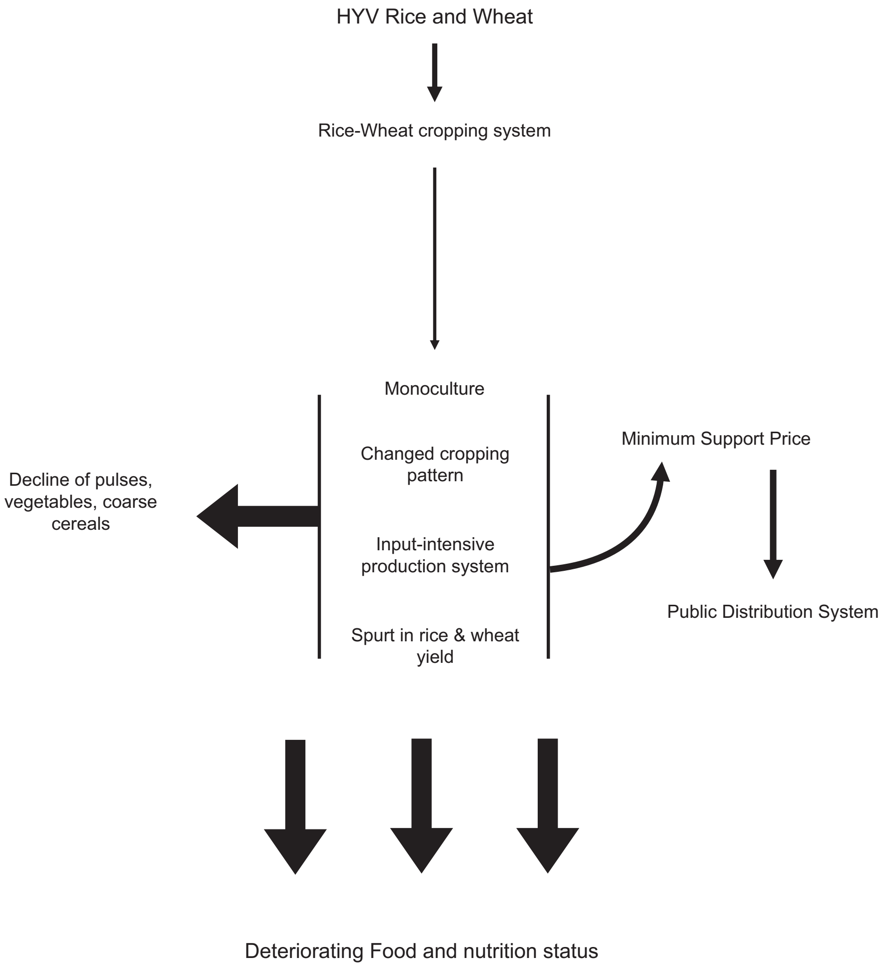

Fig. 5.5 A probable causal link between crop improvement and decline of food and nutritional security through various interacting factors

5.6.3 Seed Politics and Growing Corporate Power in Agriculture

Plant breeding technologies developing newer cultivars have permeated almost every corner of the country and are embraced largely by farmers. Be it high-yielding or hybrid seeds, or seeds with specific traits to fend off insect pests or grow in diverse agroecological systems, the Indian seed sector has become increasingly dominated by modern or improved seeds, where traditional seeds or farmers' varieties are faintly-represented (Chauhan et al. 2016b; Chauhan et al. 2017; Nagarajan et al. 2006). In other words, heirloom seeds, the regenerating propagule, have long vanished from the farmers' hands with few exceptions and so the imminent functions of seed banks or networks have been grossly disrupted. Though informal seed networks, local or small-scale seed traders fostering traditional or local seed remain instrumental in places they are exceptions rather than rules. Rural markets, village *haats* or local *shandies* (regular or weekly open-air markets), village fairs or *melas*, a cauldron of cultural diversity encouraging seed exchange, turned almost non-functional or operative in distant geographies away from industrial agricultural foci and their surroundings, or their purpose has been changed. The loss is spatially heterogeneous, some of the crops under improvement programs or direct market linkage are more affected than others (Chauhan et al. 2016b; Schöley and Padmanabhan 2017; Nagarajan et al. 2007).

Following the trails of plant breeding, the rapidly advancing domain of biotechnology and its under- or unregulated application sparked the proliferation of corporate power in agriculture and food system (Clapp 2018; Flachs 2020; Hendrickson et al. 2017; Howard 2009, 2015; Shiva and Crompton 1998). The ripples of the global agrarian change have affected the Indian seed sector which gradually became dominated by proprietary seeds developed and sold by private companies although public-funded seeds produced by the Govt. institutes still held a stake (Chauhan et al. 2016a, b; Nagarajan et al. 2007). The seed industry of India has grown enormously over the past four decades where both private and public sectors were actively involved in seed production, high-yielding varieties of wheat and rice, the hybrids of maize, millets, and various vegetables. It was supported by sound policy measures provided through the establishment of public sector organizations (Singh et al. 2019). Not as fiercely as cotton, high-yielding or hybrid seeds or seeds with disease resistance gained acceptance all over. The private sector has also started to play an important role in the supply of quality seeds of vegetables and crops, planting materials of horticultural crops, like tomato, brinjal, chilies, gourd, okra, sorghum, bajra, castor, sunflower, watermelon, etc. (Tables 5.1a, 5.1b and 5.1c).

The case of some low volume high value crops, e.g., cotton, reflects an extreme side of seed monopolization and consolidated corporate power (Murugkar et al. 2007). Post-independence, the acreage of the native species of cotton has already shrunk greatly. Cotton fields have been primarily populated by varieties and hybrids of *G. hirsutum* grown in input-intensive monocultures (Boopathi and Hoffmann 2016). After the approval and commercial cultivation of genetically modified cotton or Bt cotton hybrids, in 2002, the situation became even more critical (Gutierrez et al. 2015; Gutierrez 2018). It brought in the consolidated corporate power on seeds with the monopolization of bt seed technology initially by the Global seed giant Monsanto; afterward, a few companies stepped in to sell the bt seeds (Ramaswami et al. 2012). It was adopted like wildfire for its 'proclaimed' high productivity and has been grown in almost 90% of the Indian cotton fields, yet the claim of higher yield is deeply flawed (Kranthi and Stone 2020). Additionally, the collateral damage of Bt cotton was enormous (Stone 2011; Glover 2010). The 'success story' of higher production sparked a series of consequences at the socio-economy and ecology frontiers, i.e., an exponential rise in the use of pesticides and other agrochemicals, the emergence of new resistant pests and pathogens, burgeoning farmers' debts,

Table 5.1a The number of hybrids in major field crops developed by the private and public sector in India

Crop	Till 2001–02		2002–03 to 2009–10		Total		
	Private sector	Public sector	Private sector	Public sector	Private sector	Public sector	Share of private sector hybrid in total hybrid
Cotton	150	15	43	10	193	25	88.5
Maize	67	3	36	25	103	28	78.6
Paddy	12	4	11	5	23	19	54.8
Wheat	X	X	3	0	3	0	100
Pearl millet	60	6	22	7	82	13	86.3
Sorghum	41	5	12	8	53	13	80.3
Pigeon pea	X	X	1	2	1	2	33.3
Soybean	X	X	2	X	2	0	100
Sunflower	35	6	13	10	48	16	75
Jute	X	X	X	23	0	23	0
Mesta	X	X	X	11	0	11	0
Castor	X	X	4	9	4	9	30.8
Green gram	X	X	1	X	1	0	100
Mustard	X	X	11	1	11	1	91.7

Source: Singh and Chand (2011); Singh et al. (2019); Seeds Division, Department of Agriculture & Cooperation, Ministry of Agriculture, GOI, NSAI (2005)

Table 5.1b A few vegetable hybrids developed by the private and public sector in India (1998–2005)

Crop	Public sector	Private sector
Tomato	3	160
Brinjal	8	218
Chilli	2	73
Capsicum	1	31
Cauliflower	1	35
Cabbage	0	20
Okra	2	32
Watermelon	2	25
Cucumber	2	10
Gourds	6	80

Source: Singh and Chand (2011); Singh et al. (2019); Seeds Division, Department of Agriculture & Cooperation, Ministry of Agriculture, GOI, NSAI (2005)

Table 5.1c A comparison of total seed production by the public and private sectors

Year of production	Total seed production (MT)	Seed produced by public sector (MT)	Seed produced by private sector (MT)	Share of private sector (%)
2003–04	1.32	0.7	0.63	47.48
2004–05	1.41	0.77	0.63	45.02
2005–06	1.48	0.79	0.69	46.8
2006–07	1.94	1.15	0.8	41
2007–08	1.94	1.12	0.83	42.59
2008–09	2.5	1.51	1.0	39.78
2009–10	2.8	1.71	1.09	38.93
2010–11	3.22	1.66	1.56	48.45
2011–12	3.54	1.81	1.73	48.87
2012–13	3.29	1.61	1.67	50.76
2013–14	3.47	1.68	1.79	51.59
2014–15	3.52	1.51	2.06	58.52

Source: Singh and Chand (2011); Singh et al. (2019); Seeds Division, Department of Agriculture & Cooperation, Ministry of Agriculture, GOI, NSAI (2005)

distress, and suicides (Nagrare et al. 2009; Stone 2011). It appeared that the cotton farmers are held in never-ending spirals of debts and misfortunes.

Despite the overarching problem of the corporatization of food systems and flourishing seed sectors, informal seed systems have been functional or resurrected to different degrees at disparate geographic locations through the initiatives by village communities with the interventions of local NGOs or individual seed savers' initiatives. They play a key role in thriving community seed banks, documentation of agrobiodiversity, conservation, and utilization of heirloom seeds noting their individual properties. In opposite to proprietary seeds or industrial agriculture, they can be a good hope for climate-resilient agriculture.

5.6.4 Loss of Cultural Diversity of Food

The loss of myriad landraces of many crops tends to have serious repercussions on the cultural diversity of food. Since food is not merely the biological product grown in the field in the form of cereals, pulses, oilseeds, fruits, vegetables, and spices; it is also imbued with rich biological and cultural diversity that is closely interwoven into how we accept, consume, and enjoy our food. These attributes epitomize its cultural underpinnings. In other words, it implies how the biological components are processed or cooked, i.e., the numerous means to prepare them to suit our own meals that we relish. Therefore, food is not only a biological product that allows us to derive energy and nutrition, it embodies our cultural identity. In this realm, the loss of traditional varieties or landraces has a long-standing effect on our food culture. On a similar note, the loss of taste or related cultural attributes are also closely entwined with the food. Quite related to the notion, the significance of cultural aspects of traditional varieties has been emphasized by several researchers (Bellon 2004; Galluzzi et al. 2010; Rana et al. 2007). A review by Ficiciyan et al. (2018) underscored the choice of landraces by peasants not only due to their adaptive ability or stable yield or disease resistance but also for their cooking properties. We come across similar observations by Brush (2004) on selected potato landraces that are grown for their special culinary properties. Extinction of landraces, hence, is intricately associated with the loss of culture in the form of abandonment of certain delicacies, special cuisines, feast or ritual food, feel-good food, etc. In a recent article, Deb (2021) commented that we tend to lose our cultural diversity with the loss or extinction of rice landraces. These landraces not only encapsulate a body of folk knowledge pertaining to the distinguishing properties but also embody local food cultures and ensure food insecurity for poor and marginal farmers. Citing the example of the Philippines where a special fabric has disappeared with the extinction of the rice variety yielding the fiber, he continued that many of the delicacies have vanished with the disappearance of special rice varieties throughout Bengal. Perhaps Bengal is just one such example, the heat of agrarian change owing to newer improved, modern or elite varieties has percolated geographically and into all spheres of our life. However, the diminishing spectra of biocultural diversity with the overarching presence of modern or improved cultivars remain largely undocumented or under-researched.

5.7 Conclusion

The rapid and ubiquitous decline of agrobiodiversity has become an intense global crisis. However, the magnitude and spatial scale of the decline of selected crops have received more attention than the causal processes, therefore, linearizing the complexity of the problem that falls short of understanding the multiple actors at work and the identification of the underlying drivers. I have argued, in this article, that the change can be better viewed and deciphered through the larger political ecological lens embedded in the historical development of crop breeding and improvement leading to the global agrarian change. Though kickstarted later in India, the crop improvement programs gained impetus from the Green Revolution and garnered its ever-increasing power to mold agrarian activities. In light of that, I have struggled to outline the macro-level scientific, technological, and socio-political development that affected crop diversity through a complex web of interactions (Fig. 5.6).

In a nutshell, the analyses have broadly demonstrated the nuances of homogenization of agricultural diversity owing to the mass adoption of improved cultivars. It has portrayed how gradual progress in breeding and development of new cultivars created the necessary podium for technology transfer and adoption, how the modern cultivars swept into the field, led to the large-scale acceptance of a few, and finally ended up encompassing a major fraction of acreage. All of it happened at the cost of

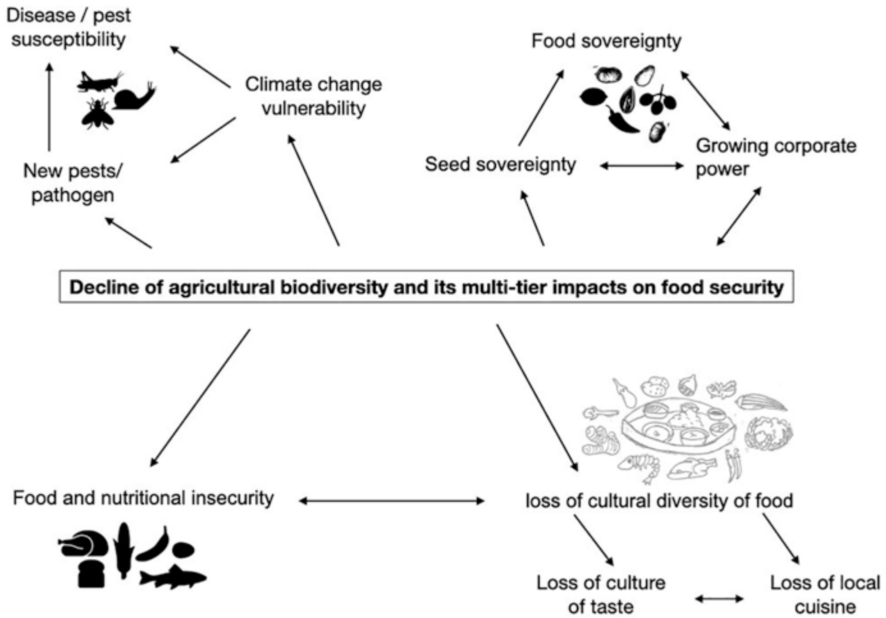

Fig. 5.6 The decline of agricultural biodiversity and its multi-tier impacts on food security through a complex web of interactions

traditional varieties or landraces used to populate the cultivation field. For many crop species (e.g., rice, wheat, potato), just a few improved cultivars held a significant percentage of acreage that resulted in severe homogenization. Although an introduction and wider adoption were largely pioneered by the Green Revolution cereals, rice and wheat, the general trend of the decline and dominance of a few cultivars have been pervasive across crops. The recent invasion of biofortified and GM crops opens up newer avenues of further decline that has been effectively portrayed by the Bt cotton. Looking closely, the productivity or yield increase seems to be the prime mover behind the improvement programs. Of various effects, I have delineated the implication of the decline in food security. On the biological ground, it emphasized the impending threats on a nearly genetically uniform pool of crops from various diseases or pests that may endanger global agriculture. On the socio-economic side, it allowed us to gain a nuanced understanding of the growing corporate power in agriculture. My analysis also recognizes the impacts on the changes in food and nutrition, and the loss of cultural diversity of food which remain an under-appreciated realms of food security policies.

In the end, the fundamental question remains whether we have any solution(s) to avert this loss. The reversal of the process of decline or slowing down is not quite an easy task with the promotion of a small suite of improved cultivars instrumental in the background. The development of newer and 'superior' cultivars by inserting novel gene(s) or fragments from the landraces or wild relatives works in tandem; it narrowly considers a few gene variations and undermines the allelic diversity within the landraces. For example, a single ‘super’ cultivar (e.g., Green super rice), a purported panacea to the global hunger problem, could further homogenize the rice gene pool and should be avoided. Rather it would count on managing diversity in a holistic agroecological framework to lessen external input usage, adhere to recycling, diversify crop package, and build resilience towards climate adaptation; merely zeroing in on the problem and emphasizing it in isolation would not be productive. The steps could hinge on nurturing conservation, utilization and management of diversity, and the activities that foster the use and exchange deserve to be adopted and disseminated. I highlight a number of related measures to enhance the use of biodiversity and associated knowledge. However, it could be fruitless unless the programs that facilitate the erosion of diversity, such as those described at length previously, are simultaneously curbed. This requires a paradigm shift, a gradual reorientation of the socio-economic and institutional arrangements that support such practices.

1. A complementary approach to embrace *ex situ* and *in situ* conservation: While a lot has been spoken about the efficiency of *ex situ* approaches and the fund has been channelized to set up genebanks, *in situ* received step-motherish treatment. *In situ* enterprises like community seed banks or seed savers’ initiatives should also be bolstered and the message should be disseminated to encourage such social movements. Empowerment of local institutions like community seed banks can be pushed to operate in a decentralized manner at the level of blocks or village-clusters serving the demand of local or regional crops and thereby harnessing the potential of heirloom seeds. It could be done at a much wider scale, local and regional levels, meeting local seed needs, engaging communities, and through the cooperations with regional agricultural stations like Krishi Vigyan Kendras (KVKs) (Fig. 5.7).
2. The premise of community seed banks brings in the necessity of heirloom seeds or landraces that are capable of growing in diverse agroecological conditions. They can offer stable and moderate yield even under not-so-favorable conditions in contrary to resource-hungry high-yielding cultivars. They retain the power to withstand climatic vagaries, or other biotic or abiotic stresses more effectively than the improved cultivars thereby insulating them from risks and instilling resilience in farming practices. The promotion and advertisement of the capacity and benefits of the traditional, heirloom, or *desi* seeds along with the extension services (like integration in natural farming or regenerative agricultural practices) deserve to be recognized in the Govt. policies.
3. Close links with the local or hyper-local markets and supply chains are to be established, they can essentially support smallholders and marginal farmers to sell their produce and encourage them in using regional agrobiodiversity. In many places, they are functional in different local avatars, e.g., village *haats* or local *shandies* (regular or weekly open-air markets), village fairs, *santes,* or *melas* are melting pots of biological and cultural diversity. They tend to encourage the sale of local agricultural produce (cereals, vegetables, etc) many of

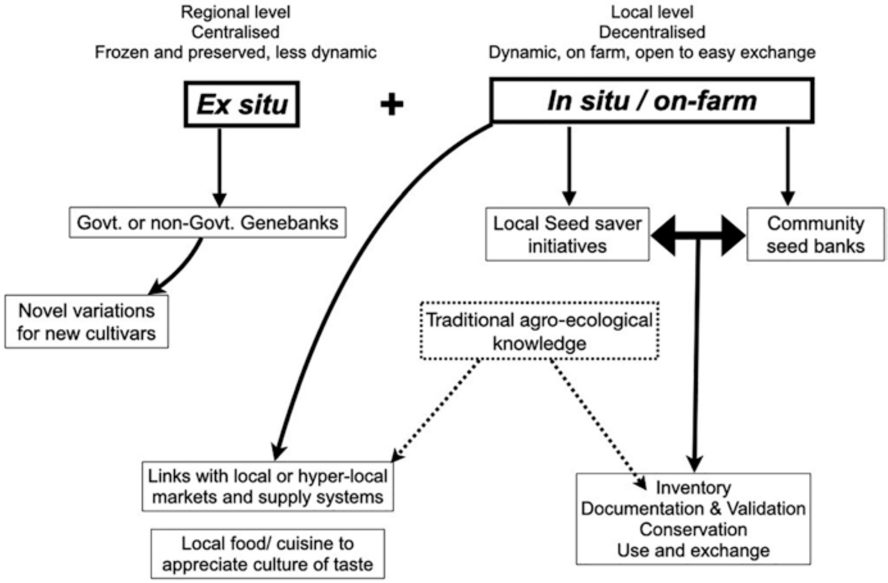

Fig. 5.7 A complementary approach to conservation and utilization of agricultural biodiversity

which could be local varieties or landraces, exchange of heirloom seeds in small to moderate quantities, and facilitate small-scale farmer producers who used to sell their excess produce. It has to be resurrected, promoted, and the message requires to be disseminated in opposition to the mass formal procurement systems (by offering minimum support price or MSP) which does not take diversity, nutritive, or cultural qualities of crops into account.

4. Invigorating traditional agroecological knowledge that is closely attached to agriculture. Transforming the notion of farmers as passive takers but accepting them as partners in agricultural endeavors is essential. They are to actively be associated with the various courses of action, like choosing varieties, participatory plant breeding, field management, resource recycling, disease containment, etc. Their central role as innovators and resolvers in local problem(s) has to be recognized and appreciated. It opens up avenues for social-innovation-driven solutions to local or region-specific problems or bottlenecks. Where a bottom-up approach could be more yielding and sustainable than the bureaucratic formulation.

In essence, agricultural biodiversity can not be conserved just as the relicts of the past or as the frozen heritage of humankind. Its survival can only be sustained through recurrent and decentralized utilization and management as well as through an appreciation of local food culture. To nurture the use of agrobiodiversity, encouraging informal cultivation or moderate management in homesteads, fringes, pastures, or fallow lands, engaging local communities, outreach, and awareness generation are essential. Besides, they can be integrated into different government interventions like nutrition gardens or kitchen gardens for small-scale cultivation and easy access. On a regional scale, '*Poshan Abhiyaan',* or the scheme for holistic nourishment under the National Nutrition Mission of the Government of India to improve nutritional outcomes of children, pregnant women, and lactating mothers can be integrated. The Ministry of Human Resource Development's 'School Nutrition Gardens' program could be another way to sensitize younger people and encourage them to grow and consume a diversity of plants as part of the schools' mid-day meals (Ray and Ray 2023). On the other hand, local culture of taste can be advertised and rekindled through ecotourism or rural tourism where people can relish 'exotic' cuisines prepared from local edible biodiversity. It could facilitate the creation of a dynamic link between consumers and producers.

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