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Importance of informal seed systems and their effect on cultivated diversity in the tropics

BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled Importance of informal seed systems and their effect on cultivated diversity in the tropics independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 18.4.2024

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Eliška Čechová

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Abstract

Agricultural biodiversity is a result of careful selection processes that farmers have been creating for over millennia combined with the pressure of natural selection (FAO 1999; Gruber 2017). It bears a crucial role in the capability to feed the world, as it carries the genetic resources essential for agriculture (Lohr et al. 2014). However, agrobiodiversity is threatened by widespread erosion. The levels of interspecific and intraspecific diversity are declining together with the vanishing of traditional knowledge (Padulosi et al. 2019). Today, agriculture is dependent on a limited number of key species, which leads to the vulnerability of food systems (Khoury et al. 2014; Henry 2017).

The objectives of this thesis were to summarize the effects of informal seed systems on agricultural biodiversity and to describe the benefits that informal seed systems bring to farmers by reviewing the available literature on the topic, including several case studies from tropical areas.

Well-functioning seed systems ensure food security for farmers as they provide them with seeds (Westengen et al. 2023). Informal seed systems are based on farmers' traditional practices and involve seed circulation (Louwaars 2017). It was concluded, that mainly small-scale and Indigenous farmers are creating, maintaining and conserving agricultural biodiversity through traditional practices of informal seed systems (Almekinders 2000; Lohr et al. 2014; Abizaid et al. 2016). Informal seed systems further ensure food security, and seed access, and support the resilience of agricultural systems and maintenance of local cultural and social values (Almekinders 2000; Gill et al. 2013; Coomes et al. 2015; Consignado et al. 2022; Zimmerer et al. 2023). Nevertheless, the importance and roles of informal seed systems still demand recognition and overall greater attention in seed laws and legislative frameworks primarily on the national level of developing countries in the tropical and subtropical areas.

Key words: seed systems, agrobiodiversity, plant genetic resources

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List of the abbreviations used in the thesis

CBD Convention on Biological Diversity

FAO Food and Agriculture Organization of the United Nation

FAOSTAT Food and Agriculture Organization Corporate Statistical Database

FSS Formal seed system

IFSS Informal seed system

IPR Intellectual property right

ITPGRFA International Treaty on Plant Genetic Resources for Food and Agriculture

NP Nagoya Protocol on Access and Benefit-Sharing

NUS Neglected and underutilized plant species

PBRs Plant Breeders' Rights

PVRs Plant Variety Rights

TRIPS Trade-Related Aspects of Intellectual Property Rights

UNDROP United Nations Declaration on the Rights of Peasants and Other People Working in Rural Areas

UPOV International Convention for the Protection of New Varieties of Plants

WTO World Trade Organization

1. Introduction

On 15 November 2022, the world's population reached 8 billion people, a momentous milestone in human development (United Nations 2022). While the increase in global population is centred among the poorest countries in the world (United Nations 2022), it is these countries that depend greatly on informal seed systems as a source for obtaining food security (Almekinders 2000; Coomes et al. 2015; Zimmerer & de Haan 2020). Seed saving as a practice of keeping seeds or other plant reproductive materials for year-to-year use has been a traditional way of maintaining farms for the last 12,000 years (Senini 2018). Farmers of many developing countries still value saved seeds to ensure their food security, moreover, exchanging and replanting is a custom embedded in ancestral traditions and rituals, often celebrated in traditional religious ceremonies (Senini 2018).

However, farmers maintaining traditional agricultural practices involving informal seed systems are confronted with many challenges, including the ongoing decrease in genetic diversity of cultivated plants associated with the state of agrobiodiversity (IPBES 2019), extreme weather conditions and other environmental shocks connected to climate change (SeedChange 2020), and restrictions established in seed laws and policies at international and national levels (Lohr et al. 2014).

This thesis aims to investigate the impact that informal seed systems have on farmers and on the diversity of cultivated plants in tropical areas to highlight their importance and critical need for wider recognition and legislative support.

2. Aims of the Thesis

This bachelor's thesis aimed to review the available literature related to the topic of informal seed systems. The thesis provided answers to two main questions. Firstly, what benefits do informal seed systems bring to farmers, their communities and livelihoods? Secondly, how do informal seed systems affect the diversity of cultivated plants?

The geographical focus was primarily set on tropical areas, however, some of the available literature cited in the thesis involved subtropical regions.

3. Methodology

The thesis was based on a systematic literature review. The suitable references were searched electronically on databases of Web of Science, JSTOR, Google Scholar, Scopus, the National Library of the Czech Republic, Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT). Primary search terms included “seed systems”, “agrobiodiversity”, “plant genetic resources”, “seed exchange networks”, “farmer seed networks”, “informal seed systems”, or “farmer seed exchange”. Further search terms varied according to the topic of individual chapters. Several case studies were analyzed to supplement the theoretical outline of the thesis. Study sites of the chosen case studies were found in the tropical and subtropical parts of Asia, Africa and Latin America. Access to the online literature resources was gained through the Czech University of Life Sciences Prague, the National Library of the Czech Republic and the National Technical Library.

4. Literature Review

4.1. Agrobiodiversity

Agricultural biodiversity, or agrobiodiversity, is a complex term comprised of several elements that interact with each other to form an interlinked system (FAO 1999). It consists of microorganisms, plants, and animals that are used directly or indirectly for food and agriculture (FAO 1999). The above-mentioned elements are perceived from the level of species to the level of genes (FAO 1999; Pautasso et al. 2013). These genetic resources were formed by traditional agricultural practices under the pressure of natural selection (FAO 1999). A wider definition of agricultural biodiversity involves species, that are not contributing to food and agriculture, nevertheless, they are supporting either agricultural production or the agricultural ecosystems themselves, as pollinators, soil micro-organisms, and other components (FAO 1999). As a result of its complexity, agrobiodiversity is enhancing the function of biological systems (Khoury et al. 2014). It is the healthy biological systems, that provide ecological services, on which humankind relies (Khoury et al. 2014; Antonelli et al. 2020).

The state of agrobiodiversity is inevitably associated with the capability to feed the world (Lohr et al. 2014) Nonetheless, agricultural biodiversity is nowadays facing severe challenges. Natural ecosystems across the world have changed under various human interventions (IPBES 2019). As a consequence of human activities, such as clearing or degrading the natural ecosystems, biodiversity loss is progressing rapidly with 2 in 5 plants being estimated as threatened (Antonelli et al. 2020). Because of this trend, biological communities are becoming increasingly similar to each other in both managed and unmanaged biological systems, which is leading to losses of local biodiversity (IPBES 2019). The decrease in the genetic diversity of cultivated crops, crop wild relatives and domesticated plant breeds is undermining the world's food security and resilience of agricultural systems to severe threats, such as pests, pathogens, or nowadays widely discussed climate change (IPBES 2019). The importance of maximising the use and access to the existing agrobiodiversity resources is becoming increasingly recognised, particularly in terms of the aforementioned climate change (Nkhoma & Otieno 2017). In Kenya and Uganda, more than 90% of interviewed farmers from both countries agree, that they have experienced climate-related challenges, resulting in adopting more drought-tolerant sorghum varieties in Kenya, which further demonstrates, that farmers are trying to use crop genetic diversity to adapt (Matelele et al. 2018). In Syria, farmers are growing a mixture of different varieties to target the specific ecological niches of relatively unfavourable dry areas (Aw-Hassan et al. 2008).

4.1.1. Biodiversity of cultivated plants

To better understand the role of agricultural biodiversity, it is crucial to overview the genetic resources essential for agriculture closely. The biodiversity of cultivated plants can be observed from the level of interspecific diversity (diversity between particular crop species) to the level of intraspecific diversity (variations within crop cultivars).

4.1.2. Interspecific diversity

Of the major taxonomic groups of plants, particularly angiosperms are the most critical taxa for agriculture and food production, concretely there are about 300,000 species of flowering plants, of which monocots and eudicots are mainly significant to agriculture (Henry 2017). Out of which, nearly 40,000 species were described as useful (e.g., edible plants, medicines, materials, gene resources, poisons, and others), while only 417 species are used as food crops (Antonelli et al. 2020; Diazgranados et al. 2020). Table 1. demonstrates the amount of plant species, that are relevant to agriculture, according to the literature. It further illustrates, that the diversity of cultivated crops that contribute to the world's food supply is narrowing significantly (Khoury et al. 2014). It indicates that, despite the high diversity of edible plants, agriculture is mainly dependent on a small number of key species, which makes the food supply more vulnerable (Henry 2017). Although the amount of the national per capita food supply is constantly increasing to meet the needs of the world's growing population, only some crops achieve the largest growth in the national per capita food supply (Khoury et al. 2014). Furthermore, despite the high genetic diversity of edible plants, FAOSTAT (2024) show that only five plant species (sugar cane, maize, wheat, rice, and oil palm fruit) form more than half of the world's agricultural production.

Table 1. Plant species relevant to agriculture

Category of plant species	Description of plant species	Number of plant species	References
Useful plant species	edible plants, medicines, materials, gene resources, poisons, and others	40,292	(Diazgranados et al. 2020)
Human food	edible plant species referred to as human food	7,039	(Diazgranados et al. 2020)
Food crops according to FAO	a limited amount of plant species recognized as major food crops by FAO	417	(Antonelli et al. 2020)
Plant species, which contribute to more than half of the world's agricultural production	sugar cane, maize, wheat, rice, and oil palm fruit	5	(FAO 2024)
Plant species supplying a key source of energy intake for nearly half of humankind	maize, wheat, rice	3	(IPBES 2019)

4.1.3. Intraspecific diversity

Observing the roots of the biodiversity of cultivated plants, the crop wild relatives stand at the beginning of plant breeding. They are wild species, from which today's crops originated through the process of domestication (Antonelli et al. 2020). Focusing further on the intra-specific diversity, it is possible to distinguish varieties and landraces. While varieties possess genotypes carefully modified by farmers and cultivated on farm areas, landraces' genotypes are more affected by the local environment (Joshi et al. 2023). Landraces are being formed and sustained by farmers and their traditional practices, including saving seeds of plants with favourable traits (Antonelli et al. 2020). As a highly genetically diverse cultivar of the same crop species (Antonelli et al. 2020), they are well adapted to the conditions of their native environment and thus increase the resilience of the farming system (Polesný &Pawera 2015; Joshi et al. 2023). Even though landraces do not produce high yields, their ability to withstand fluctuations in climate patterns is crucial to maintaining a stable yield (Nkhoma & Otieno 2017; Temesgen 2021). In Bangladesh, the Chamara rice landrace showed remarkably resilient, as it survived unusually deep-water levels during both rounds of the 2017 disastrous floods, compared to eight other rice landraces of the central Tangail floodplain region (UBINIG 2018). In the Indian Himalayas, landraces are even better yielding than improved varieties and are drought and disease-tolerant (Pandey et al. 2011). It was further described that the level of diversity of rice landraces in the above-mentioned case study increases with increasing elevation (Pandey et al. 2011).

The high variability of cultivated crops in the field provides a rich source of germplasm. This enables the breeding of new cultivars with desired traits, such as nutritional properties and resistance to biotic and abiotic stresses (Nkhoma & Otieno 2017; Gruber 2017; Temesgen 2021). Once landraces are used for the breeding of more profitable cash crops, the newly developed cultivars become more uniform, as there are only a few profitable traits maintained, which then shrinks the crop gene pools (Antonelli et al. 2020). Further causes of genetic erosion that threatens agrobiodiversity are not only monoculture cropping and market uniformity, which excludes local value chain actors from access to bigger centralised markets, but also standardisation of cultivation methods, change in food habits and marginalisation of local food cultures, or vanishing of traditional knowledge and lack of its transition between generations (Padulosi et al. 2019).

Sometimes, crop diseases and pests may also threaten landraces, as in Burundi, where some valuable and unique landraces disappeared in BBTD virus endemic sites due to the severity of the banana disease, which is further threatening the global banana gene pool (Nduwimana et al. 2022). With the decline in the diversity of cultivated plants, the dependency rates increase, and farmers lose the possibility to adapt to new environmental conditions, ecosystem changes, and new needs to overcome emerging challenges (IPGRI 2002; Gruber 2017). Conservation of crop wild relatives and landraces will preserve genetic diversity for future use, maintaining food security (Temesgen 2021).

4.1.4. Underutilized and neglected crop species

In the context of the current state of the diversity of cultivated plants, underutilized and neglected plant species (NUS) represent a possible pathway forward, according to the available literature. The broader use of neglected and underutilized species is compatible with several of the Sustainable Development Goals (particularly 2,7,13,12,15 and 17) (Padulosi et al. 2019). Neglected and underutilized plant species are wild, semi-wild, or fully domesticated crops, which were called “neglected”, as they were marginalized in the fields of research, policymaking, development, investment, and the Green Revolution, and “underutilized”, as their potential for livelihoods was not entirely discovered (Padulosi et al. 2019). 'Neglected' species are grown only in their centres of origin because they occupy unique local niches and are therefore maintained for their socio-cultural background. 'Underutilized' species were earlier cultivated more intensively; nevertheless, they became no longer competitive with other species in one shared agricultural environment (IPGRI 2002). In the case of Jericho village in the North West Province of South Africa, Jugo beans, calabash and sorghum were once planted in large quantities, but are no longer regarded as important or lucrative, mainly because of changes in food habits (for example, it was reported that local children no longer wanted to eat previously popular calabash), introduction of new crops, spread of commercial agriculture and new farming technologies (Matelele et al. 2018). Ethnobotanical surveys already described hundreds of neglected and underutilized species in many countries, yet only about 20% of them are characterized and conserved for future use in collections (IPGRI 2002).

The focus on NUS was set during the last decade, as these species started to be researched for their possible positive contribution to the resilience of agricultural systems (Ulian et al. 2020). As researchers started to observe NUS more closely, it was generally accepted that NUS possess valuable traits because they are entirely adapted to the agroecological niches of their native environment, which leads to high adaptability under the conditions of climate change (Padulosi et al. 2019). In addition, NUS are nutritionally rich and well adapted to low-input agricultural systems, which makes them highly valuable among rural communities (IPGRI 2002; Polesný & Pawera 2015). In Thailand and Cambodia, a project aiming to strengthen the informal seed systems promoted local NUS, in order to strengthen the resilience of local farming systems and subsequently increase the number of locally adapted species that households were dependent on (Gill et al. 2013). Furthermore, NUS are essential for local cultures, especially since they are used for traditional food preparation, and the know-how of their usage, collection, or preparation methods lies fully in the hands of farmers (Padulosi et al. 2019). It is estimated that approximately 70% of the world's biodiversity can be found in Indigenous People's communities, where mainly women's traditional knowledge is crucial for their conservation (IPGRI 2002; Padulosi et al. 2019). Therefore, the traditional knowledge of mainly small-scale farmers is crucial for safeguarding global agrobiodiversity (Polesný & Pawera 2015). However, as local agricultural knowledge continues to fade away, the loss of both intraspecific and interspecific diversity is notable (Padulosi et al. 2019). To achieve food security and resilience of food systems, it is important to promote and enhance the exceptional potential of NUS and protect the power of traditional knowledge to assist the preservation and more effective use of agrobiodiversity (IPGRI 2002; IPBES 2019; Padulosi et al. 2019). The informal seed systems are often the only source of neglected and underutilized species, which contribute to the intake of the vast majority of nutrients in smallholder communities (Gill et al. 2013).

4.2. Seed systems

Genetic diversity is a vital component of agricultural diversity and is of special importance to mankind because it forms the basis for all human food, animal feed, and the production of various plant products such as fibre, oils, and more (Louwaars 2017). Seeds and other plant reproductive materials are carriers of these genetic resources and therefore are essential for the entire crop production (Lohr et al. 2014; Louwaars 2017). Furthermore, since seeds contain genetic information and thus carry the essence of diversity, seed systems are using, conserving, and contributing to genetic diversity (Louwaars 2017). Since seeds are key to food and agriculture, seed sowing, harvesting, and sharing are fundamental to human development (Lohr et al. 2014). The current debates of policymakers, foundations and researchers are focusing on improving seed provisioning in order to enhance the productivity, nutrition and well-being of rural farmers in developing countries (Coomes et al. 2015). Accordingly, we can find illustrative examples of the indicated significant role of seeds in the projects of seed relief agencies, which are distributing seeds to communities to support the recovery of agriculture after sudden disasters or emergencies like drought, flood, or armed conflicts to lower the dependency on repeated food aid (Sperling & David Cooper 2003). Interestingly, the distribution of seeds from crop improvement programmes is not always successful. In some low agricultural potential and even high agricultural potential countries, large seed programs failed, and farmers were left to use seeds from their own sources or exchange them with family or other community members (Almekinders 2000). Nowadays, many development projects all over the world are aiming to improve access to certified seeds as well as strengthen the informal seed sector and pursue community-based solutions and initiatives (Coomes et al. 2015).

Focussing further on setting the definitions, the term seed system is understood as an interconnected set of activities extending from the breeding of new crop varieties to the distribution of seeds (Lohr et al. 2014). Concretely, seed systems are the means by which seeds are produced, saved, exchanged or sold in a community or country (SeedChange 2020). The main role of the well-functioning seed system is to make seeds available for farmers, which would consequently lead to assuring their seed security (Westengen et al. 2023) The development of the apparent distinction between the particular seed systems sectors started with scientifically supported plant breeding in the 20th century when the breeding efforts were set mainly on the quality and yield of a few major staple and cash crops like maize, wheat, rice, and cotton (Lohr et al. 2014). Subsequently, a commercial market for improved seeds and convenient inputs like pesticides and fertilizers was established (Lohr et al. 2014). Since the scientifically supported breeding of major staple crops began, the results are already showing double edged. As new varieties of highly productive crops were introduced, it contributed significantly to strengthening food security, however, at the cost of dependence on external inputs in seed systems (Lohr et al. 2014).

The two main sectors of seed systems are described as formal and informal. Both of them share similar characteristics, which represent the principles of the seed chain, namely the choice of a suitable variety, testing of the variety, variety introduction, seed multiplication, selection, dissemination, and storage (Sperling & David Cooper 2003). Nevertheless, the seed chains of formal and informal seed systems are not identical. In short, an informal seed system (IFSS) is based on farmers' traditional practices of selection and reproduction of plant material, and involves the sharing of seeds, while formal seed systems (FSS) occur among specialised actors, which might facilitate some steps of the seed chain such as genetic resource management, breeding, multiplication and distribution of seeds, or release of formal varieties and certified seeds (Louwaars 2017). Simply put, the formal seed system provides seeds, that are designed for commercial purposes, and their production includes packaging and marketing, whereas seeds produced in the informal seed system are unpackaged, saved by other farmers, and potentially made available in the market (Nabuuma et al. 2021). Another difference between formal and informal seed systems is the ability to clearly distinguish between seed (as a reproductive material containing an embryo of a plant) and grain (as a fruit of a plant of the Poaceae family, which is being harvested for human or animal consumption). In FSS, there is a clear distinction between seed and grain, whereas farmers of IFSS do not separate these two terms, and seeds are produced directly from the harvest and are disseminated through barter and exchange among neighbours, relatives,(Sperling & David Cooper 2003)in markets (Sperling & David Cooper 2003). Nevertheless, a sharp distinction between formal and informal seed systems does not exist, for example where public or private institutions are involved in the production of uncertified seeds (Almekinders 2000). There always exists a continuum between both of the seed sectors (Pautasso et al. 2013).

4.2.1. Formal seed system

4.2.1.1. Definition of the formal seed system

A formal seed system developed along with the professionalization of the individual steps of the seed chain (Louwaars 2017). The improvement was built on a recently gained base of knowledge in the field of plant genetics and breeding (Almekinders 2000). The simple seed chain, which comprises selection, production, and exchange of seeds evolved into a more efficient seed value chain incorporating multiple steps such as genetic resource management, laboratory research, plant breeding and testing the new varieties, production of seeds, testing the quality of seeds, seed conditioning and treating, and finally the marketing of high yielding crop variety seeds (Louwaars 2017). This modernised seed chain is highly knowledge- and technology-intensive (Lohr et al. 2014). As a result, a formal seed chain requires collaboration between the public and private sectors, particularly in developing countries where the breeding of new varieties is considered generally public and supported by international institutions (Louwaars 2017). FSS is based on ex situ seed conservation strategies, particularly gene banks (Lohr et al. 2014; Louwaars 2017). This enriched seed chain of formal seed system was designed to produce quality seeds of improved varieties to generally strengthen and improve seed production (Almekinders 2000). Formal seed system is currently being promoted by many development and agricultural agencies and policies for their possible ability to improve yields and reduce poverty (Coomes et al. 2015).

4.2.1.2. Crop management strategies in formal seed system

With regard to the plant breeds used in FSS, farmers involved in this system are working with so-called DUS varieties, which means that the genetic characteristics carried by the seeds are strictly distinct from other varieties and they express uniformly and stably (Lohr et al. 2014). Uniformity of the fields is crucial for the FSS because it simplifies crop management, particularly mechanization (Louwaars 2017). Hybrid breeds are preferred by farmers in formal seed systems for the advantage of the heterosis effect (Lohr et al. 2014). Under these conditions, FSS is able to produce seeds suitable for certification, and therefore guarantee their quality (explicitly their reliable germination, good health, uniformity, and purity of seeds) (Lohr et al. 2014). FSS forms a base for contract and export-orientated agriculture, because it focuses mainly on high-yielding varieties of a few staple crops and thus is capable of ensuring that the amount, price, and quality of harvested grains would meet consumer demand (Lohr et al. 2014). As the seeds are multiplied commercially in high quantities, the production is supported by distribution and marketing capabilities (Lohr et al. 2014).

4.2.1.3. Challenges of informal seed systems

Although all the above-named aspects seem to make the formal seed system convenient and considerably effective for the farmers, FSS contribute roughly to around 10% of seeds sowed in developing countries (Coomes et al. 2015). The reasons for such a low percentage might be various and complex, nevertheless, the available literature agrees at least on some weaknesses of the formal seed system. Firstly, many of the scientific resources mention the threat to genetic diversity. As FSS is focused on a limited number of key species for production, the genetic diversity of the field is constantly decreasing (Lohr et al. 2014). Moreover, since FSS relies upon monoculture, it is not suited well to maintain diversity itself, and consequently it poses a challenge to sustainability (Louwaars 2017). The concrete consequences might be relatively complex. Due to the homogenous cropping, ecosystem services are being threatened, and the resilience of the agroecological systems is becoming more vulnerable (Lohr et al. 2014). Yet, there are still some means that could improve the diversity and sustainability of the fields managed with the FSS. For example, diversity in formal seed systems can be enhanced by interspecific genetic crosses or by genetic modification in order to enrich the variety with desirable traits (Louwaars 2017). However, it is not only the low diversity that poses a challenge in FSS. In Vietnam, case studies show that farmers struggle to be involved in the formal seed system because they lack access to quality seeds for multiple reasons, which are the high cost of these seeds, long distances to the markets and limited participation in the seed value chains as their seeds are often of uncertain quality (Nabuuma et al. 2021; Consignado et al. 2022). Formal seed system was quite successful in developing improved varieties of the major food crops highly suitable for the generally uniform high-potential agricultural areas, but at the same time less successful in marginal, heterogenous low-potential agricultural areas with variable soil, climate and lack of access to the local markets (Almekinders 2000). In a case study from the Indian Himalayas, improved varieties are grown mainly in valleys and lower elevations where irrigation is assured, while agriculture in upland rainfed higher elevation ranges relies mainly on landraces and almost the entire seed supply is met through the informal seed system (Pandey et al. 2011). In general, rice and other minor crops (such as minor millets, pseudocereals as buckwheat or amaranths or minor legumes) of this area are so well adapted to marginal rainfed agriculture, that they play a very important role for local farmers as security food crops. Low adaptability is not the only reason for low adoption rates of some improved varieties, that were released from FSS. Other reasons are for example the fact that some varieties are simply not attractive to the farmers and possibly their own seeds were of higher quality, misestimation of the farmers' motives to buy the seeds (particularly for self-pollinating and vegetatively propagated crops), remoteness and complicated timely supply of seeds, or centralised breeding and seed programmes (Almekinders 2000).

4.2.2. Informal seed system

4.2.2.1. Definition of the informal seed system

Informal seed system (IFSS), alternatively farmers' seed system is characterised as a sum of seed production, selection, and seed exchange practices of mostly small-scale farmers (Almekinders 2000). To better understand the definition of an informal seed system, it is useful to look back at the very beginning of crop cultivation. First crops were created by the process of domestication of the native wild plant species by the early farmers (Louwaars 2017). Although domestication initially led to a decrease in genetic diversity, the following recombinations and mutations that occur naturally in plants would merge with the results of farmers' selection and breeding strategies taking place in different parts of the world over 10,000 years to eventually increase the genetic diversity of these domesticated plants (Louwaars 2017). In such manner, smallholders, as well as Indigenous farmers, are at the same time maintaining both interspecific and intraspecific plant biodiversity through the IFSS, especially in the centres of origin of particular crops (SeedChange 2020). Thus, one of the characteristical traits of the informal seed system is high genetic diversity, which then shapes the characteristics, roles, and importance of the IFSS. The above-mentioned landraces can serve as a great example of the high genetic diversity in the early stages of plant domestication and breeding. A unique interaction between the genetic composition of these varieties, farmers' practices (as selection, storage or inputs in production) and the environmental conditions (such as the inclination to drought, pests and diseases or low soil fertility) together create a system of local management of plant genetic resources where the crop development is fully connected with the seed production (Almekinders 2000). IFSS itself is a very diverse and complex sector, as it comprises local seed systems, which may vary between communities, households in a community, between crops and even between varieties (Almekinders 2000).

Seeds coming from the IFSS represent a so far dominating source of seed in the world, particularly in developing countries (Almekinders 2000; Coomes et al. 2015). Farmers involved in IFSS are prevailing across the global sample of Zimmerer K et al. (2023) 11 tropical or subtropical mountainous country study, extending from Latin America and Africa to Asia. This study revealed that the majority of studied farmers participating in the informal seed system are smallholders, including many women-headed households, often living in extreme social and ecological precarity, with a significant relation between the most concentrated IFSS utilization and the lowest GDP levels (Zimmerer et al. 2023). Other case studies also confirm that local farmers rely heavily on informal seed systems as their primary source of seeds, as in study sites of Keny and Uganda (Mlsna Zebrowski et al. 2018), South Africa (Matelele et al. 2018), Zambia (Nkhoma & Otieno 2017), Burundi (Nduwimana et al. 2022), Bangladesh (UBINIG 2018), Thailand and Cambodia (Gill et al. 2013), India (Pandey et al. 2011), Syria (Aw-Hassan et al. 2008), Peru (Abizaid et al. 2016), Colombia (Dyer et al. 2011), and Mexico (Bellon et al. 2011).

The reasons behind the persisting prevalence of the informal seed system might be for its accessibility, cost, and non-economic utility (such as social values) (Coomes et al. 2015). Furthermore, the unique adaptability of IFSS in environments with heterogenous soils, vegetation, and climate as well as in areas characteristical by aridity and topographical ruggedness is strongly associated with high levels of utilization of farmers’ seed systems (Zimmerer et al. 2023).

Moreover, the assumption that the informal seed system will eventually degrade and disappear, destined to be replaced by a formal seed system in the process of seed and crop commercialization and commerce-oriented seed legislation and regulation, was negotiated by Coomes et al. (2015). Four main factors were described to support the persistence of IFSS, which broader describe the already mentioned accessibility, cost and non-economic utility of IFSS. Firstly, seeds move through the farmers' seed systems regardless of their origin or the way they were obtained, thus seeds coming from FSS may be sold through the farmers' seed network along with the local or already creolized varieties (modern varieties fully adapted to the local conditions), forming a complementary bond between formal and informal seed system (Coomes et al. 2015). It was observed that in areas with a high risk of BBTD banana virus infestation in Burundi, banana plantlets coming from formal seed sources (such as nurseries, research institutions, NGOs, and development projects) were associated with well-branched subsequent sharing through the informal network (Nduwimana et al. 2022). The informal seed network was also an important vehicle for seed dissemination of new barley varieties in Syria, where sustainable seed supply in the dry regions on a commercial basis still represents a critical bottleneck for the diffusion of new varieties (Aw-Hassan et al. 2008). The case study further indicates that proper institutional support could strengthen the informal seed system and at the same time accelerate the adoption of new varieties (Aw-Hassan et al. 2008). In Colombia, improved varieties of cassava also circulate within the informal seed system, and the authors are raising questions about the possible spread and replacement of cassava landraces, and further point out, that vegetatively propagated crops have been largely absent in discussions on biosafety (Dyer et al. 2011). Even though it was concluded that genetically modified cassava is not likely to replace traditional landraces, there are other hazards, that should stand at the centre of attention (such as transgenes increasing cassava qualities could compromise food safety, if farmers can not recognize them, in the case of transgenes coding for industrial proteins) (Dyer et al. 2011). Secondly, IFSS is a source of seeds, which was neglected by the commercial sector (such as local vegetables or vegetatively propagated crops), and even if seeds of some commercial crops are available in FSS, farmers' seeds are still preferred for the ability of varietal choice, taste, or ease of access, and for the maintaining of social contacts and prestige (Coomes et al. 2015). Furthermore, the restrictive regulations in IFSS are often difficult to implement, and farmers hesitate to adopt them, for various reasons (Coomes et al. 2015). Finally, farmers are nowadays able to gather together and collectively push against commercialization or restrictive regulations (Coomes et al. 2015).

4.2.2.2. Crop management strategies in the informal seed system

Once a suitable crop variety is selected by the farmer for cultivation, the whole process of seed production, storage and finally re-usage of the seeds in an informal seed system remains in situ (on farm) (Lohr et al. 2014). Seed management is therefore primarily local, decentralized, and characteristical for simple breeding, selection, multiplication, and storage strategies, which are done mainly on a small scale on farm or community levels (Lohr et al. 2014). Farmers' practices such as reproduction, selection and storage serve as the basic components of the local crop development and at the same time ensure variety maintenance (Almekinders 2000). Especially women have a crucial role in practising and maintaining the IFSS (Almekinders 2000; Lohr et al. 2014; Consignado et al. 2022) and they transform the knowledge through informal channels to the next generations (Lohr et al. 2014). A case study from Uganda and Kenya reports, that female seed networks are stronger and form longer chains of seed exchange than male ones, as women often maintain ties with their former home villages, and at the same time they create new relationships once they are married in new villages (Mlsna Zebrowski et al. 2018). A very similar pattern was observed in Burundi (Nduwimana et al. 2022), Thailand and Cambodia (Gill et al. 2013), and in Peruvian home gardens (Abizaid et al. 2016),

Seeds used in informal seed systems are highly diverse on both interspecific and intraspecific levels, and as a result, the improvement of the crop characteristics is done by repeated selection of the variety with the desired traits and integration of the variety into the local gene pools (which could be done through the crossing, physical mixing in the field, or by the occasional purchase of certified seeds) (Lohr et al. 2014). Farmers need genetically diverse crops to be able to deal with the often harsh and variable soil and climatic conditions and at the same time respond to dietary needs and market demands (Almekinders 2000). Viable and diverse crop populations distributed among the communities assure morphological and varietal diversity for both staple and minor crops, which is often neglected by formal seed supply (Coomes et al. 2015). The quality of the farmers' seed is often discussed in the available literature and seems to be quite problematic, or at least uncertain. Almekinders C (2000) argue, that in many cases, seed quality in IFSS is not a problem, as the local farmers gained experience through many years of experimentation and by that time developed practices, which are very well adapted to the local conditions. Coomes O et al. (2015) add, that IFSS is able to provide quality planting materials sufficient for farmers, and in addition the seed quality in IFSS is rarely studied. The seed quality is maintained by the farmers by two spontaneous mechanisms. Firstly, the supply material high in genetic diversity is appreciated by the farmers for its unique traits (e.g. significant adaptability to local environmental conditions or distinctive organoleptic traits) (Coomes et al. 2015). Secondly, the seed quality *per se* (as seed health or germination quality) is maintained by farmers themselves, who keep and circulate only the ones of good quality (Coomes et al. 2015). Once the poor seed quality in a particular informal seed system is recognized, it can be a result of several causes, for example, inappropriate practices of production, selection and storage, lack of inputs for crop production, or insufficient storage facilities (Almekinders 2000). These problems may vary between places and between crops and the main limitation is the farmers' knowledge and experience (Almekinders 2000). However, in the summary, Almekinders C (2000) admits, that the quality of the farmers' seed is in many cases sub-optimal, and the causes vary strongly between crops and between communities. Demands for quality seed from the FSS vary remarkably between localities and over time (Almekinders 2000). Coomes O et al. (2015) agree, that there is much space to improve the quality of IFSS seeds, nevertheless, the seed quality may be poor under formal regulations as well.

Selection of the varieties is based both on farmer's decisions and preferences and on the natural selection processes (Lohr et al. 2014). Seed selection can improve the seed quality aspects and serve as a tool for maintaining the variety and potential increase of yield in genetically heterogeneous landraces (Almekinders 2000). The source of seeds for the next planting period may be on-farm (from own produced and saved seeds, which are reliable and economically attractive) or off-farm if needed in situations when the saved seeds are lost due to diseases, degradation, contamination, low yields, or simply to obtain a new variety (Almekinders 2000). The concrete sources of seeds or other planting materials might be the fields and gardens owned by the farmers, other farmers' seeds, local or distinct markets or NGOs, foundations, commercial seed suppliers, and institutions like the National Agricultural Research Systems or International Agricultural Research Centers (Coomes et al. 2015). For example, in South Africa, local seed shops play an important role in seed acquisition (Matelele et al. 2018). In Kenya and Uganda, farmers rely on their own seed resources, neighbours and local markets, and, in the case of Kenya, on farmer groups to access seeds for planting (Mlsna Zebrowski et al. 2018). In Burundi, banana farmers in the areas of high risk of BBDT virus infestation are relying upon informal seed exchange as the main seed source despite the formal efforts involving seeds sourcing from tissue culture, preferring seeds from their own plantations or from neighbours and friends providing suckers (Nduwimana et al. 2022). In the Indian mountainous Himalaya state Uttarakhand, about 95% of seeds planted by farmers originate in the informal seed system (involving seed saving, and exchanging among neighbours, friends, and relatives within the same region) (Pandey et al. 2011). It was also highlighted the positive relationship between local level seed exchange and overall genetic diversity in the region (Pandey et al. 2011). In Syria, neighbours were the most important source of seeds, and some of the farmers appeared to be nodal to the whole network (Aw-Hassan et al. 2008). Similarly, the key role of nodal farmers was reported from the Mexican state of Tlaxcala, where these farmers promote the circulation of many seed varieties of native maize, beans, and squash by carrying out a great number of seed exchanges and were the most involved in seed sharing, which positively contributes to the maintenance and conservation of agrobiodiversity (Llamas-Guzmán et al. 2022). Moreover, nodal farmers represent a valuable source of knowledge on seed maintenance, and they are active in obtaining new varieties through continuous selection or direct acquisition of new seeds (Llamas-Guzmán et al. 2022). A case study of Peruvian home gardens revealed highly differentiated access to seed sources across the communities (including seeds brought from the forest, fallow land, seeds obtained through social and personal relations, or occasional purchasing of seeds in markets), nevertheless, seed sourcing was also centred among a small group of individuals, even though the level of centralisation was relatively low (Abizaid et al. 2016). In some areas, the main plant-giver households were quite prestigious among the community (Abizaid et al. 2016). According to the studies summarised by Almekinders et al. (2000), poor farmers are often trapped in a vicious circle of seed insecurity, because the poor households are not able to save their seeds for planting as their yield is under subsistence level, and they need to seek off-farm seed sources, being forced to purchase whatever seed they can access (usually from middlemen or local grain markets where the quality of seed is relatively unknown). As in the case of Indian farmers in the Himalayas, where poor households either use their own saved seeds or are dependent on neighbours' landraces, in contrast, wealthy farmers largely use their own seeds or improved varieties in suitable lowland conditions (Pandey et al. 2011).

4.2.2.3. The mechanism of seed exchange

Once a farmer creates a new improved variety, it will soon be known within the community and there will arise requests for sample sharing, which will eventually lead to the exchange and barter of the seeds among relatives, friends, neighbours, or local grain markets (Sperling & David Cooper 2003). This seed circulation is crucial for shaping the gene flow among local varieties and maintaining the neglected and underutilized crop varieties (Coomes et al. 2015). Although it might seem that the seeds and other planting materials flow smoothly and uniformly among farmers, the reality is quite different (Coomes et al. 2015). The exchange of seeds relies upon geographical boundaries, local cultural systems, and social networks, which form a true limitation for further exchange and distribution of new varieties (Lohr et al. 2014). Practices such as gifts, barter, or traditional labour payment are performed by community members, who come from the same social backgrounds, classes, and ethnic groups (Almekinders 2000). Concretely, relations like marriage, family relationships, social statuses as widows, orphans or tenant farmers or even ethnolinguistic barriers can affect access to seeds (Coomes et al. 2015). A case study among farmers in Thailand and Cambodia reflects that poor villages tend to trade with other villages with similar socio-economic status within their ethno-linguistic lines (Gill et al. 2013). In Mexico, exchanges of seeds were primarily happening between members of the same community who knew each other, and between family members (Llamas-Guzmán et al. 2022). Moreover, farmers themselves can be selective about whom and what to share, because seeds in some areas indicate wealth, pride and identity, and in some other regions, farmers are protecting their special local varieties in so-called secret gardens, refusing to share with other farmers (Coomes et al. 2015). The age, gender and wealth of a farmer can affect the access to seeds too, some farmers can feel uncomfortable asking for seeds, whereas other more experienced farmers with wider ethnobotanical knowledge tend to give out seeds more than others (Coomes et al. 2015). As in the case of Indigenous people of Achuar in a case study of Peruvian home gardens, who were selective about who they shared with, which and how many specific plants they shared, and main plant givers were typically older, wealthier, often exceptionally knowledgeable about plants, and recognised as healers (Abizaid et al. 2016). Geographical boundaries are causing the IFSS to be relatively secluded, because even though the exchange mechanisms are (despite the social network limitation) very fast and efficient, landscape characteristics (valleys and mountains) keep the local informal seed systems isolated, lacking commercial or social contacts (Almekinders 2000).

Nevertheless, farmers are locally connected in these seed exchange networks because the exchange itself is a social process, and together they are moving the genetic diversity across the local farming units (Pautasso et al. 2013). As farmers are domesticating, creating, maintaining, and exchanging new varieties using their traditional practices, agrobiodiversity depends upon them through the continuous process of in situ conservation (Almekinders 2000; Pautasso et al. 2013). Agrobiodiversity, which is in this manner produced and distributed through the informal seed sector is a crucial and resilient source of lower-cost nutritious fresh fruits and vegetables, nourishing staple crops, and locally processed and non-perishable foods for mostly rural and poor urban inhabitants (Zimmerer & de Haan 2020). The main traits of informal seed system contributing to agroecological resilience include stabilizing yield, adaptability to extreme weather conditions and overall promotion of agroecosystem sustainability (Zimmerer & de Haan 2020).

In addition, it is not only the physical products of their work, the seeds, that farmers are sharing through the informal seed systems. The traditional knowledge associated with local seed systems represents a unique cultural heritage, which emphasises the relationship between plants and people, as seeds play an important role in the worldview of many Indigenous peoples (SeedChange 2020). In the Indigenous worldview, seeds present both biological entities and the embodiments of knowledge, culture, and the sacred, inseparably linking biodiversity and intangible cultural heritage to form a so-called biocultural heritage (Swiderska & Argumedo 2022). An interesting example of good practice of conserving the biocultural heritage is the Andean Potato Park Association, which originated by the merging of the land of five Indigenous communities to form 9,600 hectares of preserved land, aiming to conserve a rich biodiversity of native potatoes, tubers, grains medicinal plants and wildlife, through use of traditional agroecological practices (Swiderska & Argumedo 2022).

However, informal seed systems are becoming increasingly weak due to current global challenges like climate change, the disappearance of small farms, market pressures, that are not compatible with farmers' seed production and seed privatization tendencies, which altogether are leading to an erosion of farmers' seed systems (SeedChange 2020). For example, in South Africa, farmers are increasingly purchasing seeds and losing locally adapted varieties and associated traditional knowledge and skills in selection and storage due to a combination of growing food demand, climate change, environmental degradation, and results of agricultural modernization in the region (Matelele et al. 2018). Bangladeshi farmers are facing several challenges connected with climatic unpredictability (such as extreme rains and flooding, droughts and cold spells), which together with modernization of agriculture (involving main cropping systems reorientation to irrigation, monocropping and use of fertilizers and pesticides) lead to a significant loss of agrobiodiversity soil fertility, and depletion of groundwater (UBINIG 2018). In Mexico, it was predicted that climate change would have major impacts on livelihoods, that depend on rain-fed maize, particularly in the highland areas, because of the lack of the local material adapted to the predicted climate changes, indicating that farmers would need to access seeds outside their traditional geographical ranges (Bellon et al. 2011). And yet, although the IFSS is not in robust health globally, farmers are not passively waiting for the changes, and many of the characteristics of farmers' seed systems are resilient and adaptive to the new market and regulatory environment (Coomes et al. 2015).

4.2.3. Community seed banks

Community seed banks are local institutions that were designed to conserve, restore, revitalize strengthen and improve local seed systems with an emphasis on local crop varieties (Vernooy et al. 2017). Their roles vary according to the aims set by its members, such as collection, production, distribution and exchange of seeds, sharing and documenting the traditional knowledge and experience, education activities regarding the conservation of agricultural biodiversity and promotion of ecological agriculture, networking and policy advocacy, income-generating activities for members and others (Vernooy et al. 2017). Some seedbanks may also supply seeds to farmers in times of crisis, as droughts, floods, earthquakes, or cyclones (Bhandari et al. 2018). Many case studies document the role of community seed banks to small-scale farmers and Indigenous communities. In South Africa, interviewed farmers mostly appreciated the possibility of storing and conserving more seeds of their indigenous crops, reducing losses of seeds due to pests and diseases, and facilitating seed share and exchange (Matelele et al. 2018). In Zambia, informal seed systems are declining due to the introduction of new improved varieties (particularly maize), thus local seedbanks are key in the conservation of local varieties and associated knowledge (Nkhoma & Otieno 2017). Another example of the key role of seed banks in assisting the informal seed system can be found in Bangladesh. Nayakrishi Community Seed Wealth Centers and Seed Huts are institutional set up operated by the Bangladeshi non-governmental organisation, aiming to assist farmers in collecting, conserving, storing, reproducing, and exchanging local planting materials, together with documenting and maintaining associate general information, resulting in a significate contribution to seed and food sovereignty on household levels (UBINIG 2018). Community seed banks in western, central, and eastern Nepal have implemented many biodiversity management tools and approaches, such as diversity fairs, food fairs, diversity field schools, community biodiversity registers, or biodiversity management fund (Bhandari et al. 2018). Moreover, the project of Nepalese community seed banks targets eight underutilized traditional mountain crops (including amaranth, barley, buckwheat, or cold-tolerant rice) (Bhandari et al. 2018). Farmers are further supported to create a variety catalogue and varietal registry procedure, that aims to facilitate the sharing of information and traditional knowledge, which leads to better access and benefit sharing from the use of underutilized local varieties (Bhandari et al. 2018). A similar approach was applied in three Cambodian and Thai study sites, where activities such as seed fairs, regional seed banking, and organised focus group discussions led to better recognition of local IFSS, knowledge exchange, increased local awareness of food available to communities, and the value of diverse germplasm resource base to assure food security to the households (Gill et al. 2013).

4.3. Seed system regulation and farmers' rights

The ability of the seed system to maintain, use and contribute to diversity is affected by seed system regulations both on national and international levels (Lohr et al. 2014) The mode of regulation of seed systems is highly important because it has direct implications for the majority of the population engaged in agriculture and for the fulfilment of basic food needs (Cullet 2005). Seed laws are primarily designed to regulate the identity, purity and quality of seeds and govern the release of varieties of at least some major food crops (Louwaars 2017). Often, the seed legislative framework comes into focus in discussions about the possibilities of the seed sector development (Almekinders 2000). Seed and variety legislation is changing rapidly in many countries, with rules that are frequently intransparent (Lohr et al. 2014).

4.3.1. International legal frameworks and farmers’ rights

The first legal instrument aiming to fully regulate the use and conservation of biological diversity on a global scale is the Convention on Biological Diversity (CBD)

(Santilli 2017). It entered into force in 1993, a year later after being signed by 157 countries during the 2nd Conference of the United Nations on Environment and Development in Rio de Janeiro (Santilli 2017). There are three objectives formulated in the CBD: the conservation of biodiversity, the sustainable use of the components of biological diversity, and the 'fair and equitable sharing of the benefits arising from the utilization of biological diversity' (Santilli 2017). Generally, the CBD is a highly valued legal document, pointing out the role of farmers, as it emphasizes the crucial role of the knowledge and practices of indigenous and local communities in the conservation and sustainable use of genetic resources (Almekinders 2000) It became one of the most widely ratified legal international instruments, with an abundance of 196 parties (countries and dependencies) to February 2024 (Santilli 2017; United Nations 2024). Under CBD, the genetic resources are understood to be issues to sovereign rights of states, and thus the regulation of access (by whom and how are the resources accessed) is subject to national law (Santilli 2017). A bilateral agreement on the use, access and benefits of the resources is then regulated between the country which provides the resources and the party which is using them (Santilli 2017).

During the 10th meeting of the Conference of the Parties to the CBD in Nagoya, Japan, in 2010, the Nagoya Protocol on Access and Benefit-Sharing (NP) was adopted to become a legal instrument to oversee the implementation of access and benefit-sharing policies of CBD (Santilli 2017). It supports and protects farmers' rights by seeking prior and informed consent from related communities to obtain access to their resources and traditional knowledge (Bhandari et al. 2018). NP governs only the genetic resources and the associated traditional knowledge, that are already subject to regulation under the CBD and it does not apply to genetic resources, which are regulated by other international access and benefit-sharing legal instruments, that are more specialised (Santilli 2017).

The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), adopted in 2001, is an international agreement, which provides a legal instrument to oversee the access and benefit-sharing of provisions of the genetic resources (Santilli 2017). In particular, ITPGRFA is defining and summarizing the farmers' rights to seeds, as it formulates e.g. the rights to protect traditional knowledge, to participate in the decision-making processes, the right to save, use and exchange seeds, and the equitable benefit sharing from the utilization of genetic resources (Almekinders 2000).

The usage of 64 world's most important crops is governed through a multilateral system (in contrast with the bilateral system in CBD), in which all of these crops are available for free, as long as they are sought for food and production purposes (Santilli 2017). ITPGRFA cooperates with CBD policies, as the countries have sovereign rights over the seeds and biodiversity, and thus laws concerning the plant genetic resources are subject to national law (Cullet 2005). All countries involved in ITPGRFA have equal access to the genetic resources available under the multilateral system, facilitated through the Standard Material Transfer Agreement (Santilli 2017). Individuals or institutions receiving the plant's genetic resources can not establish intellectual property rights to prevent third parties from receiving the same genetic resources under ITPGRFA (Santilli 2017).

The most recent legal document safeguarding the farmers' rights is the United Nations Declaration on the Rights of Peasants and Other People Working in Rural Areas (UNDROP), which was adopted in 2018 and formulates the farmers' rights to save seeds, tenure rights over their territories and resources, the protection against human rights abuse and violence, along with economic, social, political, and cultural rights (Almekinders 2000).

4.3.2. Who owns the agrobiodiversity?

Plant breeders have always argued, that the ability of the seeds to be self-replicable enables farmers to reproduce them easily and thus they have no need to buy seeds of newly created varieties, therefore as plant breeding became more and more economically promising to attract investments of private companies, the proprietary rights over new plant varieties to ensure the exclusivity in the production and sales of these varieties came into focus (Santilli 2017). Intellectual property right (IPR) is the right of an individual or of a company to have exclusive right over the use of its own plans, ideas or other intangible assets without worrying over competition for a particular period of time (Alamgir 2017). Protection of New Plant Variety is a type of IPR, along with Patent, Trademark, Copyrights and others (Alamgir 2017). In context with the protection of plant varieties, patents and plant variety protection IPRs are mostly discussed. Plant variety protection is a tool, which legally protects a variety as such, whereas patents serve to protect plants with innovative traits, such as new genes or breeding processes (Lohr et al.

2014). The management of newly developed varieties under the IPR regime gives the breeders exclusive and monopolistic rights over the production and selling of the new variety (Santilli 2017).

In 1961, the International Convention for the Protection of New Varieties of Plants (UPOV) was adopted, enacting the so-called Plant Breeders' Rights (PBRs) or Plant Variety Rights (PVRs) (Santilli 2017). The acronym UPOV came from the French name of the L'Union international pour la protection des obtentions végétales, which founded the International Convention, as mentioned previously (Santilli 2017). In Europe, plant breeders' rights were introduced after the UPOV Convention, partially as a compromise of European states to the demand for intellectual property protection in agriculture by seed industries, as an alternative to introducing life patents (Cullet 2005). Later on, Japan, Australia and New Zealand also allowed the patenting of plant varieties, however, most countries opted for pursuing a sui generis system of the protection of plant varieties based on UPOV (Santilli 2017). The Convention was revised in 1972, 1978 and 1991 (UPOV 2011). These revisions provided stricter protection of PBRs and brought them much closer to the patent system (Santilli 2017). In the original conception, UPOV aimed to guarantee a monopoly on the commercial propagation and marketing of the registered variety, however, there was only little control over other non-commercial uses, so farmers were allowed to multiply seeds for their own use within a limitless time frame, and other breeders could freely use the protected variety for the development of their own new variety (Senini 2018). This practice is called a breeder exemption, or breeder privilege, and it essentially means that plant breeders can use any genetic material as an initial source of variation in the development of new plant variety, without the need for authorization of the PBRs holder, overall indicating that plant genetic material can be used freely, and if a new variety with at least one specific trait has been created using also the protected variety as a genetic resource, it can be produced and sold freely (in contrast with the patents, where any new invention using a patented invention can not be made without the consent of the original inventor) (Santilli 2017). For the small-scale farmers, who are practising their traditional way of agriculture through the informal seed systems, the major challenges came with the UPOV revision of 1991. There are several differences between the 1978 and 1991 Acts. The 1978 Act enabled the farmers to save the seeds of protected varieties for the next planting season without the breeder authorization, in the 1991 Act saving seeds of protected varieties is a matter of national law, which can only provide an exemption under particular conditions (without the possibility of further the exchange of seeds) (Santilli 2017). This impedes the small-scale farmers' strategy of occasionally purchasing certified seed to enrich their gene pools for the next season (Lohr et al. 2014). Moreover, the 1991 Act leaves upon the national legislative to decide whether or not can farmers reuse the stored seed for their future harvest, or that only some farmers can be entitled to use this right (e.g. some small-scale farmers), or that commissions must be paid to the holders of PBRs (Santilli 2017). The national law can under the 1991 Act further limit the size of land and the number of seeds and plant species used, hence the extent of the farmers' right to save seeds (Santilli 2017). Moreover, the 1991 Act removed the explicit prohibition of double protection (through breeders' rights and a patent) (Santilli 2017). Plant Breeders' rights are furthermore broadened by the European Council regulation 2100/94 on Community Plant Variety Rights, where farmers' rights to save seeds are restricted to approximately 20 species, and require payment of equitable compensation to the PBRs holder (with the payment exemption for the small-scale farmers, who grow plants on areas smaller than it would take to produce 92 tonnes of cereals) (Santilli 2017). Later, Community Plant Variety Rights also limited the agricultural exemption to small farmers cultivating a given volume of cereals and potatoes (Senini 2018).

Under such PBRs regime, in-situ seed production by groups or small local seed enterprises can only produce seeds once the varieties are registered, the PBRs are acknowledged (either by getting permission or paying the commissions), and seed certification and labelling have been done appropriately, according to the seed laws (Almekinders 2000). Registration and subsequent acquisition of PBRs are usually very complicated for small-scale farmers or small seed enterprises. The PBRs are exclusive and temporary, and the exclusivity extends for commercial purposes of these new varieties (which means they are sufficiently homogenous, stable in essential characteristics, distinguishable by one or several traits, and must be novel at the territory) (Santilli 2017). In principle, these requirements on the DUS character of the varieties lead to uniformity, which is undesirable for farmers (Almekinders 2000). In Addition, DUS criteria are limiting the seed production of local varieties, as the criteria for seed registration are too narrow (Almekinders 2000). Further, PBRs require a detailed description of the variety, which complicates the already complex system of a variety certification (Almekinders 2000). Usually, the development of a new variety is a collective effort in an informal seed system, and thus records are not kept about the details of the invention (Louwaars 2017). Furthermore, the variety performance testing is a problematic step, as it is often done in conditions which are quite different from the farmers' conditions (e.g. not decentralised, in favourable high potential agro-economic zones, and with use of fertilizers), criteria of the performance testing are quite restrictive and concentrate mainly on yield, overlooking other criteria essential for farmers (Almekinders 2000). In this way, farmers often do not have access to complex and expensive protection procedures in practice (Louwaars 2017).

In 1994, the Trade-Related Aspects of Intellectual Property Rights (TRIPS) was signed to become one of the main pillars of the World Trade Organization (WTO) (Santilli 2017). All WTO members must accept the legislative package including the TRIPS with no exemptions (there are currently 164 member countries) (Lohr et al. 2014; World Trade Organization 2024). The key features of TRIPS include the mandatory duration of patents being at least 20 years, patents must be granted to inventions of products or processes in all fields of technology (considering that they are new, innovative and capable of industrial applications) (Santilli 2017). All members of WTO should also provide patents or effective sui generis systems for the protection of plant varieties (Lohr et al. 2014). Both TRIPS and UPOV frameworks do not include a recognition of the communities from which the patented or protected varieties originate, which directly opposes the fair and equitable benefit sharing of the benefits resulting from utilising the genetic resources, guaranteed by the CBD (SeedChange 2020). In Africa and Asia, there remain strong pressures to permit the traditional practice of saving seeds, at least for some crops that are essential for farmers' food security, however, that would directly violate the PBRs, in addition, national laws allow patents following the TRIPS Agreement, making the situation even more complex (Senini 2018).

Senini et. al. (2018) point out another issue of the seed sector. With farmers struggling to maintain their rights to save, re-use and exchange seeds to sustain food security on one side, there are the achievements of a few biotech companies controlling the seed market on the other side (Senini 2018). This concentration of large seed companies to control the seed sector started with the spread of patents granted on GMOs in the 1990s together with a real rush of corporate merges (Senini 2018). Today, the proprietary seed market controls 82% of the world's commercial seed market (Senini

2018). Only the three largest seed companies Monsanto, DuPont and Syngenta together control over 47% of the proprietary seed market globally (Senini 2018). Genetically engineered seeds are fairly lucrative for farmers, as they are resistant to concrete herbicides, and thus provide high yields, which motivate farmers to buy the seeds together with herbicides (Senini 2018). As the seeds are fully protected under PBRs, farmers can not save and replant them and must follow strict regulations of the plant management strategies, including the use of particular fertilisers, leaving farmers no negotiating power (Senini 2018). That gives the large seed multinationals considerable power over the production of many staple crops like maize or wheat, further eliminating the native varieties (Senini 2018). In April 2017, an International Monsanto Tribunal identified abuse of human rights in activities of Monsanto, concretely breaching the right to a healthy environment, right to food, right to health, and right to freedom of scientific research (Senini 2018). Unfortunately, violation of human rights under abusive conduct of seed corporations is less evident, however, as shown above, it is increasingly understood that corporations should directly pursue human rights obligations and the imbalance of contractual, economic and political powers of seed corporations is being recognised and, eventually, slowly mitigated (Senini 2018).

4.3.3. Future of IFSS in the seed laws

There does not appear to be a simple legislative framework that would fit all countries and crops at the same time (Almekinders 2000). A well-functioning seed system is satisfying the needs of farmers, therefore recognition of the informal seed sector as an efficient seed supplier is necessary for most of the developing countries (Almekinders 2000). The formulation of the seed laws should carefully take into account the dual objectives of providing guarantees to farmers (the possibility of both quality and diverse seeds), together with creating a favourable environment for all seed producers while maintaining diversity in the field (Louwaars 2017). Arguments for changing seed policy and legislation to be more supporting IFSS might be backed by analyses of varieties and seeds used by farmers together with the identification of limitations at the community level, to better address the needs of farmers (Almekinders 2000). A Nepalese case study conducted by Bhandari et al. (2018) explores a possible format, in which community seed banks could become legitimate local institutions to facilitate prior informed consent, implement farmers' rights and mechanisms of access and benefit sharing, or support registration of farmers varieties, their certification and marketing. Seed banks are well suited for promoting linkages between formal and informal seed sectors on a local level because they have high levels of experience, skills and knowledge of local agricultural environments (Bhandari et al. 2018). Moreover, some countries have already created openings in their laws for genetically diverse seeds, which is one of the options to support IFSS, as all of the seed regulations are subject to national law (Louwaars 2017). A wide study of 14 countries in Western, Eastern and Southern Africa did, however, point out, that recognition and concrete support (such as policy, legal, technical, or financial support) of the informal seed sector is still lacking on the national level in surveyed countries, with the only exception slowly progressing in Zimbabwe. (Vernooy et al. 2023). These national seed-related policies and laws still do not describe the roles, contributions and value of IFSS as a part of the national seed sector (Vernooy et al. 2023). Despite this overall negative situation, all countries have one or more initiatives that target supporting the IFSS (Vernooy et al. 2023).

5. Conclusions

Informal seed systems and associated traditional farming practices dynamically affect both farmers and the agricultural environment surrounding them. Table 3. summarizes the benefits of utilizing IFSS for farmers that are involved in them and arranges those into main benefit categories of Food security, Seed access, Resilience and adaptability of agricultural systems and Social and cultural values. Table 4 lists the concrete effects of such practices on the diversity of cultivated plants, categorised between Creating, Maintaining and Conserving agrobiodiversity.

It is crucial that laws and policies become more open and supportive towards informal seed systems, and recognize their contributions to small-scale and Indigenous farmer communities and agrobiodiversity management. Further research on the national and community level might reveal the specific needs of farmers and possible pathways that would lead to the strengthening of local informal seed systems.

Table 5. Benefits of informal seed system

Category of the benefits	Concrete benefits of the informal seed system	References
Food security	IFSS supplies roughly 90% of seed sowed in developing countries	(Almekinders 2000; Coomes et al. 2015)
	IFSS is often the only source of NUS contributing to the intake of the majority of nutrients in smallholder and Indigenous communities	(Gill et al. 2013)
	high diversity of cultivated plants is characteristical for fields managed by IFSS, farmers are overcoming seasonality by having a high diversity of crops	(Nabuuma et al. 2021; Consignado et al. 2022)
	IFSS is contributing directly to food security on household, community, and regional levels	(Gill et al. 2013; Nabuuma et al. 2021; Consignado et al. 2022)
Seed access	IFSS ensures accessible seeds in marginal areas with heterogenous soil, climate, and topography, where FSS fails to serve	(Pandey et al. 2011; Zimmerer et al. 2023)
	IFSS facilitates seed access for the smallholder and Indigenous communities living in social and ecological precarity, a linkage exists between IFSS and low GDPR value	(Zimmerer et al. 2023)
Resilience and adaptability of agricultural systems	genetically diverse crops contribute to dealing with local climate conditions, meeting the dietary needs and market demands of farmers	(Almekinders 2000)
	traditional practices of IFSS lead to yield stability, extreme weather adaptability and general agroecosystem sustainability	(Zimmerer & de Haan 2020)

Table 2. Continued

Social and cultural values	IFSS is a social process locally connecting farmers	(Pautasso et al. 2013)
	seeds are important sources of pride, prestige, and wealth	(Coomes et al. 2015; Abizaid et al. 2016)
	traditional agroecological practices maintain and conserve traditional knowledge	(SeedChange 2020; Swiderska & Argumedo 2022)
	the cultural and spiritual value of seeds in the worldview of many Indigenous Peoples sustained by traditions, rituals and ceremonies	(Senini 2018)

Table 9. Effects of informal seed system on agrobiodiversity

Category of the effects	Concrete effects of informal seed system on agrobiodiversity	References
Creating agrobiodiversity	enrichment of local gene pools by traditional practices of selection and occasional purchase of certified seeds	(Lohr et al. 2014)
	dissemination of improved varieties through IFSS network	(Dyer et al. 2011; Coomes et al. 2015; Abizaid et al. 2016; Nduwimana et al. 2022)
	domestication of wild crop relatives as a strategy to obtain new traits in a variety	(Pautasso et al. 2013; Abizaid et al. 2016)
Maintaining agrobiodiversity	highly diverse seeds used in IFSS maintain rich local gene pools on both interspecific and intraspecific levels	(Lohr et al. 2014)
	a strong positive relation recognised between local level seed exchange and overall genetic diversity in the region	(Pandey et al. 2011)
	seed circulation is crucial to the geneflow of landraces and maintenance of NUS	(Coomes et al. 2015)
Conserving agrobiodiversity	domesticating, creating, maintaining, and exchanging new crop varieties enhances agrobiodiversity through a continuous process of in situ conservation	(Almekinders 2000; Pautasso et al. 2013)
	local seedbanks are assisting with agrobiodiversity conservation through diverse projects and activities	(Nkhoma & Otieno 2017; Vernooy et al. 2017; Matelele et al. 2018)

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