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Recovering *res communis from res propia*: how does open source seed contribute to farmers' seed rights and breeding for diversity?

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Abstract
The current complex seed governance framework, and the increasingly oligopolistic seed industry that has championed it, have created a series of seed enclosures that exclude farmers and many breeders from freely accessing, sharing and improving seed, and constraining their freedom to operate and cooperate. Opposing the resulting ongoing loss of both cultivated diversity and farmers' seed rights, experimental initiatives applying open source models and copyleft principles to the domain of seed have emerged. This article presents six initiatives from five different continents applying open source seed (OSS) models in very diverse cultural, policy and agronomic contexts: Bioleft in Argentina, Seed Savers Network in Kenya, MASIPAG in the Philippines, OpenSourceSeeds in Germany, Open Source Seed Initiative in the USA and Rete Semi Rurali in Italy. We analyse the mechanisms by which OSS models attempt to overcome legal, knowledge, and financial enclosures by creating safe operating spaces in current governance frameworks, breeding for diversity and rebuilding bridges between farmers and breeders, while exploring innovative financial models to fund breeding for cultivated diversity. The findings show that OSS emerges as a synergistic strategy to amplify seed rights through three dimensions: first, geographically, by connecting local and international efforts to enhance cultivated diversity and seed rights. Second, a temporal dimension, by acting now, within the current legal context, while contributing to the long term transformation of seed governance. Third, through its capacity to be applied in both physical and digital realms. Finally, further areas of research on OSS are proposed.

Keywords Open source seed · Copyleft · Breeding · Commons · Biodiversity · Cultivated diversity · Farmers' rights · Seed systems · *res communis*

Abbreviations

ABS	Access and Benefit Sharing
CBD	Convention on Biological Diversity
CSB	Community Seed Bank
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
DSI	Digital sequence information
DUS	Distinctness, Uniformity and Stability
EU	European Union
FAO	Food and Agriculture Organisation
GESENI	Gene Silencing based on ENcoded protein's Intracellular localisation
GOSSI	Global Open Source Seed Initiatives
IPR	Intellectual property rights
ITPGRFA	International Treaty for Plant Genetic Resources for Food and Agriculture
MLM	Multilateral Mechanism
MLS	Multilateral System
MTA	Material Transfer Agreement
NP	Nagoya Protocol
OHM	Organic Heterogeneous Material
OSS	Open source seed
PGRFA	Plant genetic resources for food and agriculture
TK	Traditional knowledge
UNDROP	United Nations Declaration on the Rights of Peasants
UPOV	Union for the Protection of New Varieties of Plants
VCU	Value of Cultivation and Use

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Introduction

Porque sé que nadie puede sembrar con los puños cerrados.
Para sembrar es necesario abrir las manos.

Because I know no one who can plant seeds with closed fists.
To sow we must open our hands.

Adolfo Pérez Esquivel
Nobel Peace Prize Acceptance Speech, 10 December 1980

In his speech accepting the award of the 1980 Nobel Peace Prize, the Argentinian human rights activist Adolfo Pérez Esquivel chose the metaphor of sowing seed to express his conviction that generosity and an open hand are the necessary path to the just and humane "new society" that he envisioned (Esquivel Pérez 1980). This poetic assertion can be read quite literally onto the contemporary circumstances of plant genetic resources for food and agriculture (PGRFA). Throughout most of agricultural history, cultivated plants and their seeds have been shared by farmers and breeders with an open hand as a form of *res communis*, things held in common due to its low excludability – such as the atmosphere, the high seas or outer space - overall free to save and share, with no legislative framework to regulate them until the first seed laws were introduced in the XIX century (Ku 1990; Fowler 2000; Brush 2004). Some authors have provided interesting historical accounts of the close links seed-as-grain still had in state developments and international power even without specific seed-as-planting-material policies. Thus, it is important to state the difference between seeds as "grain" and seeds as "planting material". For example Scott (2017) has analysed the key role that cereal grains as legible, calculable, visible, commodity that could be stored – and, especially, taxed – as facilitators of state formation. In this case, the multifaceted seed is considered in its manifestation as consumable grain, not as planting material. Indeed, harvested grain has been *res propia* for most of agricultural history. But seed as planting material evolved from *res communis*, to *res nullius*, to increasingly *res propia*, originally freely shared and exchanged everywhere until the emergence of the commercial seed industry and associated intellectual property regulations and laws. Therefore, prior to the establishment of seed laws, individuals may have possessed plant varieties, but they did not hold legal ownership or exclusive rights to improve, reproduce, or commercialise them.

Thus, though subject to traditional and customary arrangements for access and use, the broad sharing of plants and seeds among and between farmers and communities over time and space resulted in the rich and astoundingly diverse pool of crop genetic resources that has undergirded and still is critical to modern agricultural development and productivity (Scott 1999). The violent appropriation of plants - as well ashuman beings and land - was a hallmark of colonial expansion (Brockway 1979). The crops and landraces and seeds of farmers and indigenous peoples were taken with impunity as if they were *res nullius*. The legal term *res nullius* refers to something not owned by anyone but that can be claimed and appropriated. As modern plant breeding developed, gene banks were filled with seeds that were collected by plant scientists from public and - increasingly - private organisations employing gentler collection methods justified by the notion that such genetic resources were the "common heritage of humankind" (FAO 1983; Engels et al. 2011). This euphemism put a *res communis* gloss on what was still de facto *res nullius*, for collection entailed no respect for customary traditions of access or to any form of payment or reward.

Fast forward to the 1970s, when an increasingly powerful private seed industry and its state allies started to engineer a qualitative shift in the common character of PGRFA. Seeds were reconstituted from the *res communis* into *res propia*, i.e. things that are privately owned and from which others may be excluded (Kluge 2005). The resulting formal seed system - supported and subsidised by the policies of national governments and philanthro-capitalist foundations - has eroded and widely replaced farmer-managed seed systems worldwide (Mushita and Thomnpson 2019). The subsequent replacement of landraces and locally adapted cultivars by genetically vulnerable hybrids and new commercial varieties (that must be distinct, uniform and stable - DUS) reduces social equity, cultivated diversity, and environmental resilience. Although the private takeover of seeds is still incomplete and uneven, it is often all too effective at preventing farmers and breeders from accessing, sharing, and using PGRFAs freely and creatively.

This increasingly aggressive corporate enclosure of the seed continues to be resisted by farmers, indigenous peoples, civil society organisations and by certain state actors in low and middle income countries, who work hard and persistently to limit the impact and spread of the privatisation of seed, such as La Via Campesina, ETC Group, European Coordination Let's Liberate Diversity, and Navdanya amongst others (Kloppenburg and Kleinman 1987; Kloppenburg 1988 [2004]; No Patents on Seeds 2020; Shiva 2020; La Via Campesina 2024; ETC 2024; ECLLD 2024). A key result of these resistance efforts is illustrated by how the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) established farmers' rights to save and share seed as a principle – though not an operational element – of international law (FAO 2004).

However, these efforts have so far only managed to slow down, not reverse, the advance of the dominant, unjust and unsustainable, industrial seed system (Laird et al. 2020).

Nevertheless, the formal seed sector seems to be arriving at a critical inflection point that is opening space for serious change in thinking and policy. The exceptionally aggressive use of patenting by the largest of corporate seed actors over the last decade has produced a "patent thicket" in which no one – including competing companies – is sure of what is patented and by whom (USDA 2023), triggering a "tragedy of the anti-commons" (Heller 1998; Heller and Eisenberg 1998; Beck 2011; Kock 2021). Access to germplasm and "freedom to operate" is further constrained by multiple possibilities of encumbrance from contractual and administrative obligations. Furthermore, the rapid emergence and widening use of new genetic technologies - such as Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) - and the question of how Digital Sequence Information (DSI) will fit into the intellectual property (IP) framework further complicates matters (Aubry 2019; Wynberg et al. 2021; Aubry et al. 2021; Ambler et al. 2021; Ajates 2023). In a recent book, the former head of intellectual property rights (IPR) for one of the largest global seed firms argued that "system failure can only be prevented by a fundamental redesign of the IPR system for plant innovations" (Kock 2023:377). Similar appeals from government and academic actors are now common: e.g., for "a fundamental rethink" of seed system development (Norwegian Ministry of Foreign Affairs et al. 2021) and for privileging "commons over private ownership" as an agrifood system principle (Wirz et al. 2017; Mazé et al. 2021; McGreevy et al. 2022; Ajates 2023; Sandström et al. 2024). The brittle character of the existing IPR system for plant innovation has also been challenged by the United Nations with its 2018 United Nations Declaration on the Rights of Peasants and Other People working in Rural Areas (UNDROP), which explicitly recognises farmers' rights as human rights (UN 2018; Fakhri 2022).

In this unstable and malleable space, we interrogate the emergent potentialities of open-source seed (OSS) as a mechanism to convert seed into *res communis*, i.e. things held and owned in common (Kluge 2005). Drawing upon experiences from different continents, we analyse the implementation of the OSS idea in practice with the aim of contributing to the recovery of seeds as common goods. We discuss empirical and theoretical arguments across three dimensions of enclosure - legal, knowledge, and financial - facing PGRFA. We unpack how various initiatives across the world have developed and agreed upon a set of operational principles to guide their efforts in diverse policy and geographical contexts and circumstances. Then, we identify both the opportunities and challenges facing OSS, and in doing so, address the key critiques that the OSS model has encountered (e.g. Tsioumani et al. 2016; Louwaars 2019; Kock 2023). We provide a reflection on how OSS strengthens the larger seed sovereignty movement, and our understanding of its compatibility with international agreements on farmers' rights. Finally, we point to the abundance of future research topics relating to OSS that are becoming increasingly relevant as the climate and environmental crises and the digitalisation of nature and society unravel.

Open source seed: a concept and a movement

Although "farmers' rights" are enshrined in international law through the ITPGRFA, these rights are largely rhetorical. In practice, farmers' abilities to access, save, use, exchange, and sell seed have been progressively and radically restricted by a wide range of arrangements in national domestic laws and regulations. The principal mechanism by which the transformation of seed from de facto *res nullius* to *res propia* has been achieved, and continues to be, is the application of law. IP laws that extend patent rights to seed material have received much attention, as patents are normally the most restrictive form of IPR on other potential users. But patent law is quite uneven around the world. More ubiquitous are IPR laws providing for "plant breeders' rights" (PBRs) that limit or exclude access to and use of the protected seed. The use of PBRs has been given global reach though a wide variety of international and regional treaties, agreements, and protocols. Over the last five decades, the International Union for the Protection of New Varieties of Plants (UPOV) has increasingly and very successfully lobbied for PBRs. A reflection of the widespread international imposition of their rules is the fact that adherence to UPOV is often made a condition of trade and foreign aid agreements (Peschard et al. 2023). Contract law provides an additional layer of control via material transfer agreements[1] (MTAs) and related instruments. Virtually no genetic material now moves between formal public or private institutions without an accompanying MTA. Contractual arrangements appear in a variety of forms including licences, technology use agreements and bag tags (Kloppenburg 2014).

The efficacy of IPR and contract law in foreclosing farmers' access to seed and restricting or prohibiting further sharing or exchange is dependent on a country's enforcement capacity and political will. Since many lower income countries lack robust enforcement arrangements, the circumscription of peasant and indigenous farmers' access to and freedom to use seeds is being achieved less by IPR

[1] MTAs are legally enforceable contracts specifying the conditions under which germplasm is provided from a supplier to a recipient.

and contract law than by administrative law and simple rulemaking (Borowiak 2004; Tripp et al. 2007; European Parliament 2017; Peschard 2023). Laws and administrative regulations create phytosanitary and varietal standards, marketing arrangements, and testing protocols that require skills and financial resources that many smallholder farmers lack. Often, some form of official "registration" for a variety and/or the seller is required for sales of seed to be permitted in the market. In some cases, "national catalogues" of approved varieties are created, which, to be included, are required to comply with strict standards of distinctness, uniformity and stability (DUS), making illegal the sale or exchange of seed of varieties not listed (Chable et al. 2012; Christinck and Tvedt 2015; Sievers-Glotzbach et al. 2020; Batur et al. 2021; Sandström et al. 2024). Collectively, the legal, policy, and administrative arrangements are different manifestations of the historical and ongoing enclosure of the seed. This enclosure of seeds affects not only farmers, but many other savers of seed, including university breeders, non-profit organisation breeders, independent breeders, small company breeders, indigenous breeders, hobby seed savers, and gardeners. What is at stake in the struggle over access to seed is not simply the right to save and replant seed on the farm, but the right to breed, and locally adapt crops in an increasingly changing climate and depleted agrobiodiversity.

The OSS concept arose from an ambition amongst several seed advocates to create a seed-sector analogue to the free and OS software sector's use of copyright and contract law, which permits open access to original source code and to any subsequent modifications and derivatives (Douthwaite 2002; Deibel 2006; Aoki 2008, 2009; Boyle 2008; Kloppenburg 2010). Established in 1992, the non-profit social enterprise Cambia was the first to enact an operational OS modality in 2005 that could be applied to seeds and genetic information. Cambia made biotechnical innovations available under OS licensing arrangements that "democratise problem solving to enable diverse solutions through decentralised innovation" by ensuring "both freedom to operate and freedom to cooperate" (Cambia 2024). Building on those ambitions, the concept of OSS has been unfolding over the last decade, via initiatives that have sought to explore how OS ideas can be applied to crop plant germplasm (Aoki 2008; Kloppenburg 2010, 2014; Kotschi and Rapf 2016; Luby and Goldman 2016; Kotschi and Horneburg 2018; Kotschi 2020). Broadly, OSS are seeds whose distribution and/or sale are accompanied by a formal commitment to preserve the rights of farmers and breeders to freely use, save, replant, and improve them. Critically, this responsibility is extended to all of their progeny and derivatives.

The OSS concept has been enacted since 2013, and at the time of writing, is operational in different continents and contexts. In order to provide an international forum for mutual learning and support, organisations involved in exploring and promoting OS approaches to seed, formed the Global Open Source Seed Initiatives coalition in 2020, yet not legally incorporated (GOSSI 2024). GOSSI amalgamates the efforts of the following initiatives:

- Open Source Seed Initiative (OSSI), USA, https://osseeds.org
- OpenSourceSeeds - Agrecol, Germany, https://opensourceseeds.org/en
- Bioleft, Argentina, https://www.bioleft.org/en/
- Rete Semi Rurali (RSR), Italy, https://rsr.bio
- Seed Savers Network, Kenya (SSNK), https://seedsaverskenya.org
- MASIPAG, Philippines, https://masipag.org/

These groups have adopted a set of core principles that provide both consistency and flexibility in the construction of its members' operational arrangements in their diverse cultural, agricultural, legal, and political contexts (GOSSI 2024):

1. OSS are plant genetic materials subject to the expressed and explicit commitment – legal, ethical, or organisational – to maintain maximal freedom to use the seed and any of its derivatives.
2. Anyone may freely use OSS, that is, grow it, save it, propagate it, develop it further, use it for breeding, and sell it.
3. Recipients may not privatise the seed or its progeny through exclusive IPR or other use restrictions.
4. Recipients must assign the same rights and obligations to subsequent recipients.
5. The breeder(s) of OSS shall be recognised through attribution of credit.

In this paper, we present an overview of these six diverse initiatives with data collected through two methods: first, observant participation (Seim 2024) by the authors, who have been involved in at least one of the GOSSI initiatives since the beginning of their formation and/or GOSSI, as well as seed system research. Second, GOSSI members and the wider RSR team ran a face-to-face two-day workshop in Florence in July 2023 to exchange the objectives and barriers faced by the OSS model and by each of the OSS initiatives, as well as the theoretical commonalities across them. The discussions from this workshop were transcribed by one of the authors and validated by all attendees, and then coded accordingly to the theoretical framework of seed

enclosures that we present below. As researchers with a collective long-standing engagement in seed governance, seed research and the OSS movement, our positionality inevitably shapes both our access to the field and our interpretation of the data collected. This proximity has provided us with unique opportunities for deep active participant observation and the ability to gain insight into informal dynamics, organisational challenges, and underlying motivations within the OSS community. However, we also recognise that such closeness can introduce bias, particularly in framing or interpreting the OSS initiatives in a more favourable light. Thus, rather than striving for detachment, we acknowledge our embeddedness as a strength for uncovering nuanced, emic perspectives, while also being cautious of the need for analytical distance (Chavez 2008). In this light, we have actively sought to present both the promises and tensions inherent in the OSS model. To achieve this, we adopted a reflexive approach, critically reflecting on our dual roles as researchers and participants, as well as carefully listening to other external colleagues' critiques of the OSS concept, and revising the grey and academic literature for arguments questioning the application of open source mechanisms to seed. We collectively prepared and revised the format and content of a template to collate data across the same dimensions for each initiative. The templates were completed with data obtained from ongoing participation and meetings within each initiative, their strategy documents, their OSS contract/pledge text where applicable, and website content. Additionally, some of the authors collaborate with other OSS initiatives as well as the one they directly are members of, offering a complementary perspective. Two of the authors are members of GOSSI but not directly related to any of the six initiatives presented, offering a wider perspective and objectivity.

To frame the findings, we apply the concept of seed enclosures. Ajates (2023) has analysed how logistical, legal, financial, social and technological enclosures of PGRFA have been evolving over the last century. As new technologies emerge, new digital enclosures, such as DSI, amplify older and well-established enclosures, determining reach and type of farmers' rights and fair access to seed. We build on this work to assess these OSS initiatives' attempts to overcome these challenges, applying a bifold analysis: first, we provide an overview of each initiative in Table 1, reporting on the following categories: start date, number and type of members, policy context, use of OS and activities. Second, an adapted version of Ajates' enclosure framework is applied to discuss empirical evidence relating to three types of enclosures: first, legal enclosures, with their underlying epistemological and governance frameworks; second, knowledge enclosures across breeders, farmers and researchers, including the challenges and opportunities of new genome editing techniques and digital technologies; and third, finance enclosures, unpacking the need for innovative financial models that can support resilient seed systems and cultivated diversity. The paper does not aim to compare the OSS initiatives – which are presented as illustrative and exemplary cases (Yin 2014) – but to illustrate the richness and diversity in which OSS models can be developed and implemented. Nevertheless, comparisons will emerge to highlight specific factors relating to the socio-economic, agronomic and policy context of the initiatives that shape - and in some cases determine - their objectives, activities and use of OSS.

Findings and discussion

Table 1 provides a summary of the key aspects and activities of the six Open Source Seeds Initiatives members of GOSSI.

Drawing on our experience developing, participating in and researching the initiatives presented above, this section discusses the findings as empirical evidence to analyse how the OSS model and movement is implemented in practice, while also addressing key challenges and critiques. To provide a comprehensive analysis, we consider the findings across three dimensions, in relation to three different levels of seed enclosures that determine farmers' rights and fair access to seed (Ajates 2023): legal, knowledge and finance enclosures. In doing so, we aim to also identify overlaps with other movements working towards seed rights and cultivated diversity in order to find further synergies for mutual support.

Overcoming legal enclosures: creating new spaces in current governance frameworks

The six OSS initiatives illustrate how there are two principal forms of operationalising OS ideas for seeds: a licence (OpenSourceSeeds and Bioleft), and a pledge (OSSI and Rete Semi Rurali). MASIPAG and SSNK are still considering the most appropriate form for their large network of members. The licences consist of a contract stipulating that the receiver of OSS seeds is allowed to do whatever they wish with the seeds, the only constraint being that they must grant the same freedoms to others when making further transfers of the seed and any future derivatives. Generally, the licences take the form of an MTA contract between two parties that can be enforced by law (Fredriksson 2021). In the case of Argentina, as a compromise to engage more diverse types of breeders, Bioleft has developed three licences, two of which - in the absence, for now, of alternative mechanisms for revenue generation - restrict

Table 1 Open Source Seeds Initiatives members of GOSSI

Initiative	Open Source Seed Initiative (OSSI)	OpenSourceSeeds - Agrecol	Rete Semi Rurali (RSR)	Bioleft	Seed Savers Network Kenya	MASIPAG
Country	United States	Germany	Italy	Argentina	Kenya	Philippines
Start date	2012	2012	2007	2018	2017	1985
Members	50 breeders and 72 seed companies, as well as a seven-person Board of Directors.	63 members and a seven-person Board of Directors. Target groups are organic plant breeders, seed producers within the EU and other stakeholders of the food value chain, including consumers and the general public.	40 members, including nonprofit and profit organisations dealing with dynamic management of agrobiodiversity.	Public sector plant breeders, agricultural extension workers, farmer-breeders, urban/peri-urban market gardeners, an IP lawyer, and an interdisciplinary group of researchers.	More than 2,500 farmer groups with approximately 58,000 members, the majority of whom are women.	Over 500 farmer organisations, 48 NGO partners, 20 church-based development organisations, 35 scientists-partners. MASIPAG is active in 49 of the country's 80 provinces, reaching more than 40,000 farmers.
Policy context	The US has no strict regulations on plant breeding/seed sales, which has enabled a dynamic community of independent farmer-breeders who freely develop, market and sell new cultivars, often through their own small seed companies. New varieties can be protected by PBRs and utility patents; US follows UPOV 1991.	In the EU, varieties must be listed in an official catalogue to be sold in the market legally. Agricultural species are also subject to VCU testing. The EU distinguishes four categories of varieties: 1) commercial varieties (which must comply with DUS criteria); 2) conservation varieties 3) amateur varieties; and 4) populations (OHM). All are included in the official catalogue. PVP can only be given to commercial varieties, and it is optional. Alternatively, all four categories – including commercial varieties - could be protected by an OSS Licence. The EU system follows UPOV 1991, with strong enforcement and regional harmonisation.		In Argentina, varieties must be listed in an official catalogue to be legally marketed, and have to fulfil DUS criteria. Agricultural species must also be tested for their VCU. New varieties can be protected by PBRs, and genetically modified DNA sequences can be patented; the country follows UPOV 1978.	In Kenya, varieties must be listed in an official catalogue to be legally marketed, and must fulfil DUS criteria. Agricultural species must also be tested for their VCU. New varieties can be protected by PBRs; follows UPOV 1991. Sharing or sale of farmers' varieties is illegal.	In the Philippines, varieties must be listed in an official catalogue to be legally marketed, and must fulfil DUS criteria. PVP can be implemented for commercial varieties. The country is still not a UPOV member. There is to some extent legal protection for traditional farmer practices. Seed corporations calling for stronger proprietary rights.

Table 1 (continued)

Initiative	Open Source Seed Initiative (OSSI)	OpenSourceSeeds - Agrecol	Rete Semi Rurali (RSR)	Bioleft	Seed Savers Network Kenya	MASIPAG
Use of Open Source	OSSI's OSS tool is the Pledge which must accompany all distributions of seed of its Pledged varieties, along with the text: "You have the freedom to use these OSSI-Pledged seeds in any way you choose. In return, you pledge not to restrict others' use of these seeds or their derivatives by patents or other means, and to include this Pledge with any transfer of these seeds or their derivatives."	The strategy is to protect newly released varieties with an open-source licence, which is an MTA under civil law. So far, varieties of various crops have been licensed. A beneficiary clause allows the licence holder, namely, Agrecol, to pursue licence infringements of any seed transaction. Thereby copyleft can be legally enforced, since the same protection applies for any progeny of the OSS variety.	RSS started using OSS in 2017. RSR has developed diverse populations through EU projects Solibam and Diversifood, now marketed under a copyleft pledge similar to OSSI's. Seed packets include information on origin, breeding process, and use conditions. RSR aims to extend the OSS model across the food value chain by labelling products made from these populations. It also uses the ITPGRFA framework to manage seed access through its Community Seed Bank.	Bioleft uses a copyleft licence attached as a clause to an MTA for novel seed transfers. It has developed three licence versions, all requiring that seeds and derivatives remain freely available for breeding and own use. Two versions restrict commercial multiplication, accommodating public breeders needing exclusivity for funding and farmer-breeders wanting to prevent third-party sales. This compromise enables diverse participation while exploring alternative revenue models for open-source breeding.	Unregistered local cultivars of various crops have been described and thereby given an identity. Farmers are managing such cultivars as open source by exchange of seed. A system to register farmer varieties as open source is in preparation.	MASIPAG has developed its own Seed Policy and Declaration of Farmers' Rights, supporting the OSS model as a means to strengthen farmers' seed rights through seed commons. Although it has not yet implemented an OSS pledge or licence, MASIPAG is actively exploring this path. This interest has intensified in response to a proposed amendment to the SIDA, which could bring farmers' seed systems under formal regulatory control.
Activities	OSSI partners with breeders who commit to distributing at least one variety under the OSSI Pledge. These breeders include the pledge in their catalogues and marketing. OSSI only pledges new varieties, ensuring traceability and monitoring of use. Its website features pledged varieties, breeder recognition, and seed partner links. OSSI also raises awareness about the value of "freed seed" through education and outreach to farmers, gardeners and the general public.	OpenSourceSeeds provides advisory support to plant breeders, seed producers and other stakeholders of the food value chain. It does lobbying and public relations. In addition, the financing of open-source plant breeding has been a key area of research for this initiative. Since 2020, Agrecol also cooperates with Seed Savers Network Kenya to adapt the open-source strategy to the Kenyan context; thereby, Agrecol contributes to testing the OSS model as an avenue to enhance Farmers' Rights in different continents (Kotschi 2020).	RSR fosters dialogue, collaboration, and knowledge-sharing among actors who value agricultural diversity. It supports collective management of agro-biodiversity, promoting diversified systems from seeds to diets, including processing and distribution. RSR began by advocating for conservation varieties, seeking their legal recognition based on their value to organic farmers. The network's efforts aim to "release diversity" by strengthening seed systems and food practices rooted in ecological and cultural richness.	Bioleft is building an alternative seed system through collaborative breeding, production, and distribution, focusing on maize and tomato. It links public breeders with farmers and market gardeners. A key strategy is a co-designed digital platform that maps seed networks and facilitates exchange, traceability, and knowledge sharing. The platform also collects performance data from diverse sites to support participatory breeding through monitoring, evaluation, and distributed learning.	SSNK strengthens farmer-managed seed systems and Farmers' Rights through capacity building, support for seed enterprises, and community seed banks. It is developing an online platform featuring 65 farmer cultivars, protected as commons to ensure free access for breeding. Its work includes identifying and documenting local varieties, supporting informal seed exchange and marketing, and promoting open-source strategies. SSNK also trains farmers and engages in advocacy, targeting diverse stakeholders including government and NGOs.	MASIPAG was founded as a response to the Green Revolution's negative impacts in the Philippines, promoting a "people before profit" philosophy. Accordingly, the network promotes farmers' rights by collecting, conserving, and evaluating indigenous, heirloom, and local seeds of rice, maize, vegetables, and tubers. It coordinates seed exchanges and farmer-led rice breeding. Community-managed trial farms and seed banks serve as training hubs and spaces for knowledge exchange between farmers and researchers each year.

Source: Own elaboration

recipients from multiplying seeds for sale (Bioleft 2024a). In other cases, these exchanges often take the form of non-contractual, symbolic agreements through the pledge, largely because of practical and political challenges to use a legal licence in some jurisdictions. Whether in the form of a copyleft licence or pledge, the ambition of these initiatives is to create an expanding pool of germplasm available to all who agree to share seed as *res communis*, in perpetuity.

A key issue is the ability to dissuade or impede others from infringing OSS copyleft rules. To be enforced, a licence must be able to be read, understood and formally agreed to, and this must happen with every transfer of seed or planting material. Due to its low excludability, it is very easy for PGRFA to be transferred without a formal agreement (Halewood 2013), in which case licensing agreements cannot be enforced. Furthermore, whilst a licence is, in principle, legally enforceable, a pledge is not (Sievers-Glotzbach et al. 2020), although it "is intended to create a moral obligation" (Kock 2021:271) to comply. Even though not equally enforceable, an OSS pledge is likely to deter companies from using pledged OSS because institutional IPR offices typically wish to avoid any complications or uncertainties about who owns what. Infringement of copyleft rules on OSS is thus, not an issue of "unauthorised use" of OSS material (since anyone can use OSS for whatever purpose) but rather, it would refer to efforts by firms to privatise OS germplasm, or its derivatives, and so prevent those who developed and use that material from continuing to breed from and use it. Since seeds represent a unique type of commons that has co-evolved through millennia of collective human-natural selection practices (Halewood 2013; Tschersich 2021; Sandström et al. 2024), the OSS 'copyleft' feature safeguards seed as 'protected biocultural commons' (Montenegro de Wit 2019; Cambia 2024); ensuring their availability for unrestricted use and countering corporate attempts at privatisation.

The ITPGRFA was introduced as a way of creating a semi-commons for seeds, where states can make accessible PGRFA over which they exercise sovereignty. A frequent misunderstanding of the OSS model is that some critics point out that PGRFA are already OS, when referring to the "facilitated access" granted to the material under the Treaty. The difference with the OSS model is that the access granted by the Treaty only applies to a generation of material, leaving future derivatives vulnerable to misappropriation and privatisation. The OSS copyleft mechanism applied by these initiatives, by contrast, is a departure from the existing legal and governance framework because it converts seeds into a viral modality of *res communis*, and is, so far, the closest existing mechanism in the current global context to ensure collective ownership in perpetuity. The strength of the OSS model is that it provides a proactive mechanism - complementary to the ITPGRFA Multilateral System (MLS) that excludes a large portion of commercially available PGRFA - to secure seed rights in the current legal context created by the ITPGRFA, creating spaces to operate while global efforts to improve the international legal framework continue.

For example, at the time of writing, OSSI in the US had a portfolio of over 550 OSSI-pledged varieties and additional cultivars continue to be added. In Europe, RSR and OpenSourceSeeds have protected various grain varieties with a pledge and a licence respectively. OSS in Germany has developed two rye and two wheat populations. In turn, RSR started a project on evolutionary populations in 2010 in collaboration with other EU organic organisations aiming to breed for diversity and challenging the uniformity paradigm in breeding and agriculture (Bocci et al. 2025). This movement succeeded in opening a novel legal space in the European Union, thanks to the European Commission's decision to create a temporary experiment for marketing the seeds of these populations. In 2017, one organic farmer from RSR's network certified the first non-uniform seeds in the EU. This idea of using non-DUS varieties found a new permanent space within the 2018 Organic Regulation, which created a new category of varieties: Organic Heterogeneous Material (OHM), based on this previous work on populations. Moreover, the regulation defined organic varieties as varieties specifically bred for organic farming and not just conventional varieties certified as organic. RSR has developed three organic populations (barley, durum and soft wheat). It is too early to see the value chain impact of the OHM pledge, although an early success is that all the diverse actors involved support its rationale and aim. RSR's ongoing work on diversity has been recognised at the European level in the seed marketing regulation proposed by the EU Commission in 2023. This text contained many new derogations for allowing diversity into the seed market, such as the first reference to the dynamic management of diversity by farmers and participatory plant breeding (European Commission 2023, 2024).

The viral nature of OS models contributes to opening resources and cooperating with other efforts to protect farmers' seed rights. OpenSourceSeed in Germany and Bioleft in Argentina have shared their licences online, enabling others to use them and adapt them to their contexts (OpenSourceSeed 2016; Bioleft 2024a). OSSI in the US and RSR in Italy have done so with their pledge text (RSR 2022). In the US, the Indigenous Seed Keepers Network has used a revised version of the OSSI Pledge on some seed packets of native cultivars that they distribute. In Oaxaca (Mexico), the Espacio Estatal en Defensa del Maíz Nativo de Oaxaca has publicised the OSSI Pledge and has recommended its use

when indigenous seed is sold or gifted to strangers (Espacio Estatal 2021).

The use of OS and copyleft ideas to release seed material has occasionally received some concerned critiques for different reasons. One of them is that OS is a concept that has not arisen from struggles over natural resources, but is instead associated with digital and IPR frameworks with roots in Western contract law (Kloppenburg 2014; Conti 2023). This critique overlooks the broader contexts and grassroots character of some of these OSS initiatives, as well as the ways they intersect with resource-related struggles over seeds. Furthermore, OSS initiatives' inspiration from the digital commons and open-source software is not really an alien link, as these digital social movements in turn build on the idea of the commons and the cooperative movement that originated in alternative food systems nearly two centuries ago (Ajates 2017; Ajates González 2017). Another critique is that the copyleft imposition could also be seen as an "ownership" claim since it is claiming "dispositional authority" (the right to determine the rules of access) over a variety. Furthermore, by ruling out any restrictions on seeds in perpetuity, OSS could also be considered absolutist - i.e. overreaching and with no time termination date - even potentially destructive of customary arrangements, and contradicting the commons (Louwaars 2019; Kloppenburg 2014). These OSS initiatives' way of operating suggests that in practice, OSS models do not in fact impose any obligation, other than keeping seed accessible.

Similarly, Demeulenaere has argued that the fact that OSS is based on property regimes and laws might make it cumbersome for small farmers, suggesting that a more promising strategy would be to continue to pursue farmers' rights at national and international levels (Demeulenaere 2014, 2018). While this is a valid and relevant aim, unfortunately, decades of activist efforts have not halted the erosion of cultivated diversity and farmers' rights. Over the last century, humanity has lost 75–90 percent of vegetable and fruit crop varieties (FAO 2010; Montenegro de Wit 2016; FAO 2019a). Additionally, the funds arising from the Convention on Biological Diversity (CBD) and Nagoya Protocol (NP) are not actually meant to be specifically allocated to PGRFA but to biodiversity at large, nevertheless, only small amounts of finance for biodiversity projects have been raised by the Access and Benefit Sharing (ABS) system of the CBD, as well as from the ITPGRFA Benefit Sharing Fund (Rabitz 2017; FAO 2019b). Thus, the current governance system might be facilitating access to PGRFA but is not being effective at preserving and promoting cultivated diversity, securing farmers' rights, nor is it fostering fair innovation. OSS provides a new space for resistance in an area where few channels and tools exist to provide an alternative to the privatisation of PGRFA.

Seeds are naturally a non-rivalrous good, since their use by one person does not diminish their availability to others (Halewood 2013). Unlike private goods, seeds can be saved, replanted, and shared without being consumed in the process. However, IPR and other legal restrictions have artificially transformed seed into rivalrous goods. OSS enables seeds to be reclaimed as natural non-rivalrous common goods. Furthermore, many indigenous people and other communities embedded in farmers' seed systems already have to operate within the current global seed governance model, seed marketing rules, certification schemes, breeding policies and phytosanitary rules (Nishikawa and Pimbert 2022; La Via Campesina 2024). Within this space, OSS offers a novel, proactive mechanism for creating favourable legal spaces in which the unencumbered sharing, use and improvement of seed at the local level can be practised. In fact, the analysis of OSS mechanisms and initiatives reveals how these are not in competition with, but rather complementary to, ongoing struggles and legal tools at the global level such as the ITPGRFA, CBD, NP and UNDROP. The preambular paragraphs of UNDROP are an illustration of this alignment, in which it is recognised that access to land, water, seeds and other natural resources is an increasing challenge for rural people, and stressing the importance of improving access to productive resources and investment in appropriate rural development. Article 19 of UNDROP elaborates seed rights, while also reiterating that states shall ensure that seed policies, plant variety protection and other intellectual property laws, certification schemes and seed marketing laws respect and take into account the rights, needs and realities of peasants and other people working in rural areas. OSS aligns and contributes to implementing those rights by generating and maintaining copyleft PGRFA and breeding for diversity. As we have found in the initiatives presented in Table 1, OSS also helps catalyse debate about, and raise public awareness of seed issues. Additionally, OSS contributes to solutions to overcome current legal enclosures - at least partially - through the creation of new favourable legal spaces at the local, national and regional level, such as the EU's new OHM legislation. It is important to highlight that OHMs are, by definition and legal requirement, non-uniform. Consequently, they are intentionally exempt from complying with DUS requirements and therefore do not qualify for protection under conventional intellectual property rights. OHMs are legally in the public domain and are well aligned to the OSS principles.

Another critique of OSS is that the model can be seen as enabling seed characterisation and registration, which in some contexts with farmer-led seed systems can be a precursor to introducing farmers' varieties into official restrictive systems, along with the associated Western epistemology of having a protective rather than a sharing approach to seeds

(Wattnem 2016). This valid criticism reflects the shortcomings of the current legal and financial globalised framework dominated by a handful of powerful actors that severely influence how seeds and biological resources are governed and traded. Farmers' seed systems that are still not threatened by corporate appropriation and registration regimes should be supported and encouraged to continue and reinforce their own farmer-managed practices. For those farming communities where current or emerging national seed policies threaten their own seed systems, such as the case of MASIPAG and SSNK, OSS can serve as a model that allows those communities to manage seed in their own terms and continue to use legally use it, regardless of who else might wish to enclose their germplasm. For example, traditional varieties in Kenya that were not yet registered have been given identity through a description as part of SSNK activities, and on that basis, innovation can be claimed and an OS licence can be attached to avoid exclusive appropriation by industry or public actors. The SSNK is characterising seeds following the standardised method, while also exploring other farmer-led descriptors more relevant to their local communities.

Thus, the introduction of OSS models into lower income countries with stronger informal seed networks can contribute to strengthening the farmer-managed seed sector, legally and politically. The OS licence provides protection against appropriation of local crop cultivars that are increasingly taken by public research institutions, to be bred for uniformity, then registered and put under Plant Variety Protection. For example, SSNK is at the time of writing working with a group of farmers who have brought a court case challenging the constitutionality of Kenya's seed and variety law that prohibits and even criminalises the sale and exchange of peasants' seeds by the farmers that have developed them (SSNK 2024; Kloppenburg 2024). In the Philippines, seed corporations are calling for the amendment of the country's Seed Industry Development Act (SIDA) to ensure seed proprietary rights are enforced (MASIPAG 2024), which could bring farmers' varieties under formal regulatory control. MASIPAG's stand is to not go with the amendment, as it goes against MASIPAG´s principles and system. MASIPAG believes the amendment should secure strong farmers' rights and seed freedoms. Those in favour of the amendment - such as large seed companies - ask for seed registration through NSIC (formerly Philippines Seed Board). As part of the advocacy work, MASIPAG is reaching out to some farmer groups and NGOs that support the amendment in order to explain the implications. In preparation for potential legislation changes and new registration laws, MASIPAG is exploring OSS as a mechanism to protect their own varieties.

In many low-income countries, the changing policy environment towards privatisation of seed and planting materials under UPOV-styled PVP laws puts local seed savers at a critical juncture. For instance, India's *Protection of Plant Varieties and Farmers' Rights Act of 2001 (legislated in compliance with the WTO TRIPS Agreement)* recognises farmers as breeders, however, their varieties are also brought under the IPR regime through registration of farmers' varieties (complying with DUS criteria), a category of extant varieties. Thus, many farmers' organisations and local seed saver groups are confronted with the dilemma to either register and get PVP on farmers' varieties, or keep their varieties out of this IP-driven framework of 'protection' premised on the UPOV Convention. In such a situation, having the option of an OSS system could be a way forward. Without a tedious framework needed to set it up, all it would warrant is a declaration by the national government that all farmers' varieties are the country's shared biocultural and agroecological heritage, i.e. res communis, and cannot be restricted by IP mechanisms. This would also remove the burden on farmers to register under the PVP law.

Many years of energy and thinking have been dedicated to developing the ITPGRFA in a way that could offer a robust framework to protect cultivated diversity. The path dependence is profound and individuals and organisations that have spent so many resources into the governance arena do understandably consider risky dispersing efforts on alternatives. In that sense, OSS can be perceived as a transactional and bilateral mechanism that is separate from and could undermine multilateral approaches, posing a distraction from the important negotiations being played out on the international policy stage. OSS models can also be seen as slowing down an alternative framing of seeds and biodiversity to which access is based on collective rights versus economic cycles and IPRs. In this section, we have considered these perspectives, and presented empirical evidence of how OSS can be complementary to existing policy frameworks that have a different scope, such as the ITPGRFA and NP. At the same time, OSS models can enable a change of mindset for seed movements by opening a policy space away from the money-for-access discourse, instead focusing on creating safe spaces to legally operate, protect and generate cultivated biodiversity. Thus, OSS offers not only pre-emptive protection in the current law and policy framework that farmers have to deal with today, but also a positive call for a global seed paradigm change for a vibrant biodiverse seed future.

Overcoming knowledge enclosures: breeding for diversity and rebuilding bridges between farmers and breeders

The removal of legal impediments to the free circulation of seed is a critically important enabler of farmers and plant breeders' freedom to operate and to cooperate. However, it is unlikely to be sufficient to catalyse the development of a diverse and active community of breeders located across the public sector, the farming community and locally embedded companies, engaged collectively in developing diverse and resilient seed systems. An ongoing decline in funding and personnel in public institutions is compounded by increasing restrictions on freedom to operate associated with MTAs and restrictive licences (Shelton and Tracy 2017). This declining capacity of public plant breeding not only forecloses the development of alternative cultivars, but also weakens the prospects of innovative cooperation with farmer breeders in participatory breeding programs (Jones 2004; Ceccarelli 2015). Critically, by restricting access to germplasm to these actors, the seed industry reduces the social and biological innovation space to produce the new plant cultivars that will be required to respond to and adapt to a world experiencing very rapid social, agronomic and climatic change (Mastretta-Yanes et al. 2024).

There is more knowledge in seed systems than just the genetic information embodied in germplasm (Sievers-Glotzbach and Christinck 2021). Knowledge also takes the form of skills and competencies about how to adapt, breed, cultivate and maintain varieties. These breeding skills and competencies cannot easily be shared, they must be learnt over time. The control of this skill set has shifted over the last century: first, it moved from farmers - often women - embedded in peer-to-peer seed systems to professional breeders in the public sector, and then from the public sector to the private sector, and to what now is just a handful of giant seed firms. This transfer of the loci of knowledge on seeds from the farm to the laboratory comes with legal, socio-economic and gender implications (Swiderska 2018; Ajates 2023). The OSS model recognises that all seeds and the associated traditional knowledge humans hold of them, are the collective result of centuries of wisdom and breeding by diverse communities that have generously and freely shared them. OSS is an effort to acknowledge, value, maintain and build on that tradition and those freedoms and practices for present and future generations.

Therefore, cultivating diversity will require efforts not only to free germplasm but also to redistribute breeding skills and competencies across a wider group of actors to overcome the knowledge enclosures that characterise formal seed systems (Ajates 2023; Mastretta-Yanes et al. 2024). All the OSS initiatives share a set of values that emphasise sharing, openness, collaboration, and the inclusion of women's knowledge. The initiatives seek to challenge the way in which seed innovation takes place, moving from private to more collaborative channels, focusing not only on how to do plant breeding in more collaborative ways, but for whom, and with whom, and for what ends. For example, Bioleft fosters experiments where farmers shape breeding goals alongside public sector plant breeders and researchers, documenting their observations on the network's open-source digital platform (Cremaschi and van Zwanenberg 2020). Bioleft also facilitates access to seeds and knowledge: via making visible and accessible the broad diversity of seeds and associated knowledge in their digital platform catalogue; mapping different farmer-breeders across Argentina in their online platform; and disseminating relevant material via videos and handbooks. Furthermore, the Argentinian initiative also contributes to fostering innovation by connecting existing dispersed breeding capabilities and facilitating new ones, e.g. by linking farmers and urban/peri-urban market growers who were not previously engaged in breeding with professional breeders, and through training and collective experimentation.

OSSI in the US has generated recognition and legitimacy for their community of freelance breeders through extensive outreach in publications, newsletters, podcasts and social media (OSSI 2025). Likewise, the work of SSNK is actively exploring how OSS models could more proactively include and link small farmers and community breeders, and their farmer members are learning to describe their own varieties with standard descriptors as well as developing their own local ones. SSNK has been collaborating with the Kenyan National Seed Bank for several years. Recently, the National Seed Bank has recognised the need to legalise farmers' varieties. SSNK is currently looking into developing and establishing a registration system for farmers' varieties in parallel to the registration of commercial varieties under DUS. This would allow farmers to trade their seeds, a practice which so far has been illegal in Kenya. Also, in this process, a "seeds as commons" regulation - in which open source could be a potential option - is being discussed, a step forward which would prevent farmers' varieties from privatisation. In these critical junctures, OSS can offer the constitutive structure of a registration framework for farmers' varieties by enabling the creation of a "protected commons" to "keep the genetic material in the public domain" (De Jonge et al. 2025:7). So far, SSNK farmers have been experimenting with the OSS pledge, although they are still considering what OSS mechanism would better fit their objectives.

In the case of MASIPAG, their successful approach to farmer-centred seed systems is based on setting up and managing community seed banks that are continuously looking to expand. The network has collected and bred over 2.000

rice varieties, maintained by member farmers, with more than 600 traditional rice varieties. 1.299 new rice varieties have been bred, 506 of which through participatory breeding. MASIPAG has been able to train 70 rice breeders from whom nine breeders have become trainers themselves and are currently training young people as apprentices. Currently, 20 farmer rice breeders and 12 farmer-corn breeders continue to develop new rice crosses and improved traditional maize cultivars respectively.

These initiatives operate in a global context in which corporate control over breeding knowledge and practices has wide implications for agroecological transitions. Although, some policy attention to low external input farming has increased in the face of the biodiversity and climate crises. For example, the EU's Farm to Fork Strategy aims to shift 25 percent of EU farmland into organic production by 2030. With the focus on changing farmers' growing methods, less attention has been paid to who is going to breed for, and how, for such a widespread organic transition to be successfully achieved. OSS offers an innovative model based on collaborative breeding between public sector and agroecological and organic farmer breeders, the latter of whom often share an affinity with the values of sharing and the commons that underpin OSS. These collaborations can help make the most of the policy window that is opening for innovation in organic farming and seed systems.

In formal seed systems, it is the breeder's labour that justifies the breeder's right to determine conditions of use of their new variety. Yet, this fails to honour and recognise the previous labour, breeding skills and centuries that went into developing most of any variety's genetics. Ensuring open access to new varieties in perpetuity can be a way of honouring the common heritage that unites past and future communities of breeders and growers. Copyleft licences can also be explored for communities, rather than individual breeders. Thus, OSS may offer a pathway for blurring often fixed identities in apparent opposition i.e. breeders versus farmers, as well as encouraging some farmers interested in breeding to become farmer-breeders. In many of the OSS initiatives, the impetus for experimenting with OS models came from small independent breeders or farmer breeders, rather than from public sector breeders employed in research institutes and universities.

A key obstacle OSS initiatives face to develop more collaborations with public sector breeders is that they are required by their institutions to use IPR to protect new varieties, and to transfer plant material to the private sector, both to earn income for their employers, but mainly as part of the knowledge transfer metrics that researchers are assessed against. Yet often these varieties are then shelved, or if commercialised, royalties are not collected due to the administrative costs. OSS models offer breeders concerned about their freedom to operate, and who wish to collaborate beyond the established corporate seed sector, the space to release new material as OSS. In doing so, OSS initiatives will need to consider how they can provide recognition to different types of breeders. For example, although public breeders are not credited with technology transfer recognition from OSS varieties, and their employers do not earn royalties, their work can be recognised by the ongoing global institutional efforts to support and value the development of science with and for society. These efforts include the increasing adoption of the San Francisco Declaration on Research Assessment (DORA) framework by states - an international declaration encouraging a move away from citation metrics to social impact as a way of assessing the quality of research –, the 2021 UNESCO Recommendation on Open Science, and a general participatory turn towards engaging societal actors in research projects (Ajates et al. 2025); these new standards and metrics are changing attitudes to conventional ways of doing and measuring research impact in universities (Wehn et al. 2024; DORA 2024). For example, in Argentina, public sector breeders who are collaborating with Bioleft have reached an agreement with their institutions so that they can count the number of hours they dedicate to participatory breeding as research hours. Additionally, their efforts are often reported in newspapers and other media, offering recognition of the dissemination of their research findings to wider society (Bioleft 2024b).

From a technology perspective, the rise of new technologies in synthetic biology - such as biobricks - and new genomic techniques (NGTs) - such as CRISPR-Cas9 - is fuelling the dematerialisation and fragmentation of PGRFA (Ajates 2023). At the time of writing, the EU was advancing legislation on CRISPR and NGTs (European Parliament 2025). The proposed legislation excludes NGTs from organic production. A significant point of contention was the patentability of NGT plants. The European Parliament proposed excluding all NGT plants, parts thereof, genetic information, and process features from patentability. This sparked a heated debate, with some arguing that banning patents could hinder innovation and investment in research and development. In response, the Council of the EU suggested a compromise that introduces some transparency in patent information (European Parliament 2025). Final adoption is still pending discussions with the Trilogue, including the European Parliament, Commission and Council; however, this patentability compromise will contribute to increasing the already severe "patent thicket", against which OS emerges as an alternative.

At the same time, new genomic techniques are creating new opportunities, challenges and paradoxes for seed governance. One such paradox is the OpenCRISPR initiative - the world's first OS tool for gene editing - which aims

to provide customizable gene editing proteins designed by Artificial Intelligence and large language models (Business Wire 2024). These proteins are molecules inspired by nature but that have never existed before (Hale 2024). Its OS dimension, if and when applied to cultivated plants, might satisfy concerns about corporate patenting of genetically modified crops, but still does not solve the problem of knowledge enclosures, given a likely further narrowing of the diversity of breeders with the skills to use the new technologies, or indeed, overcome complex concerns about potential long term environmental and health risks still unexplored for gene-edited plants. It also overlooks the challenges posed by the simplification of natural cycles that happens in laboratories, resulting in unforeseen plant reactions, such as Gene Silencing based on ENcoded protein's Intracellular localisation (GESENI). GESENI is a recently identified phenomenon in plant reproductive biology by which certain transgenes in sperm cells are selectively silenced by the host plant, highlighting the complexity of biological systems and putting into question the effectiveness of NGTs (SeedWorld 2024). OS gene editing tools for crops also compete in funding with the conservation of existing and long-standing locally adapted traditional varieties.

DSI is another technological development posing a challenge to global seed governance. DSI does not have an official definition, but the term is widely used to refer to the digital representation of genetic material—such as DNA, RNA, or protein sequences—stored and shared via databases (Ajates 2023). DSI plays a critical role in biological research, biotechnology, and conservation but raises policy debates about access, benefit-sharing, and equitable use of genetic resources globally. A decade-long complex international debate continues to agree on how to overcome the governance and legal vacuum created by DSI, since the current PGRFA legal framework was developed for physical rather than digital seeds. At COP 16 of CBD in October 2024, Parties adopted the establishment of a multilateral mechanism (MLM) for benefit-sharing from DSI, including the creation of the Cali Fund. This fund aims to support biodiversity conservation and sustainable use, with at least half of the resources allocated to Indigenous Peoples and Local Communities (IPLCs). Operationalisation efforts are underway, and the first review of the mechanism's effectiveness is scheduled for COP 18 in 2028 (CBD 2024). In relation to DSI, the Third World Network has warned that the current SMTA does not capture benefits arising from the use of PGRFA DSI, and that failure to regulate DSI will mean that the Treaty will never be able to ensure protection for farmers' rights and prevent the patenting of genetic resources contained in the Multilateral System, provided in the first place by those very same farmers. It highlighted that the CBD's multilateral mechanism for sharing the benefits of the use of DSI is unfortunately based on voluntary rather than mandatory payments, which would not make it any more effective than the current Treaty mechanism (TWN 2025).

Thus, DSI also reveals further parallels between the OS model for seeds and the digital commons, enabling new imaginaries for the management of digital copies of seeds through copyleft principles, and creating synergies with wider digital commons communities and data democracy struggles beyond food and agriculture (Laird et al. 2018; Ajates 2023). The openings for OSS in the increasing digital sphere of PRGFA are significant. An example is OSSI's current efforts to sequence its pledged varieties to be able to accurately identify OSSI germplasm should it get exclusively appropriated. At higher levels of governance, opportunities for DSI as commons could also be paradigm changing. For instance, national, regional and community public gene banks could host OS DSI databases of local OSS PGRFA in the future. Regional innovative extension services could be broadened to include participatory breeding and sequencing, so that the benefits of DSI are rematerialised in the fields, and the cycle between farmers and DSI is closed and mutually beneficial. DSI and OSS could be developed across complementary infrastructure: physical OSS often rely on public or community-based seed banks and participatory breeding programs. Fair access to OS DSI (e.g., genetic data of traditional varieties) can promote fairer and more locally adapted breeding. From a legal and ethical perspective, as the DSI MLM evolves, it could provide the legal backing for OSS to access and use sequence data without IP encumbrances (Nehring 2022). In return, open-source frameworks can serve as implementation models for equitable use of DSI, showing how fair licensing and community-based stewardship can work in practice. Furthermore, the infrastructure built for DSI benefit-sharing (e.g., tracking use, distributing funds via the Cali Fund) could also support OSS initiatives by ensuring recognition, compensation, or reinvestment into farmer-led innovation and *in situ* conservation. It is important to highlight how open access DSI should go beyond FAIR (Findable, Accessible, Interoperable, Reusable) Principles, and adopt UNESCO Recommendation on Open Science along with the CARE (Collective benefit, Authority to control, Responsibility, and Ethics) Principles on Indigenous Data Governance, to ensure DSI is shared and used as a digital common good (RDA 2019; TWN 2025). In summary, DSI opens both biodigital piracy risks as well as opportunities to scale up the OSS model, and future-proof it for the growing digital dimension of PGRFA.

Overcoming economic enclosures: exploring innovative financial models

Across most of the world, seeds, once part of in-farm and community resources, have become another expensive external commercial input for farmers. OSS models disrupt the economic enclosures that IPRs create - although not those erected by seed registration and certification requirements - and which imply high seed prices for farmers, and expensive or restricted access to germplasm for farmers/breeders who wish to adapt and improve varieties. Yet, in eliminating the financial incentives that have enabled plant breeding in the private sector through IPRs, a key challenge is how to fund OSS systems, and how to financially encourage breeders who otherwise might be committed to cultivated diversity - and oppose IPRs for seeds - to adopt the OSS model, when it is unclear how they might be able to cover the costs of their breeding activities, let alone turn a profit (Louwaars 2019; Agrecol 2022).

These perceived limitations to the financial dimension of OSS, mainly around investment recovery and profitability also highlight the underlying limitation of the current funds-for-access governance model, i.e. that biodiversity conservation is effectively expected to pay for itself (Laird et al. 2020). While the legal framework cannot be solely blamed for the reduction in cultivated diversity, financial pressures cannot be underestimated. A recent review study identified how economic and policy factors do seem more important than climate change in explaining the worldwide decline in cultivated diversity, particularly landraces (Calvet-Mir et al. 2025). The authors identified that structural agricultural policies lead to farmers' dependence on markets and new technologies, causing the erosion of landrace diversity and an overall disregard for indigenous and local knowledge. Fairer and more effective models for financing on farm conservation and breeding for diversity must be found, since all evidence suggests the current ones are only working for some dominant players and rapidly reducing cultivated diversity (Bocci et al. 2025).

The initiatives presented combine a variety of income streams: project grants, collaborations with paid academics, seed sales, etc. There is a common misconception that OSS are seeds free of charge. OSS are freed, not free-of-charge seeds. Indeed, most of the farmers and breeders involved in these OSS initiatives sell their OSS were legally able to do so, either online through their own website, or face to face through local networks and markets, and to other actors in the supply chain, such as like-minded small seed companies. OSSI in the US works with breeders-seed companies that sell their own varieties to farmers as well as to other breeders. They are selling to a market that values their organic and local cultivars. These breeders are already connected to the right value chains. Similarly to the new opportunities for OHM in Europe, OSSI breeders have been selling early populations before they are uniform. They make contracts with a larger seed company for a variety with the OSS pledge. They get a financial return by being first movers before farmers start multiplying the new variety themselves. Still, a major challenge is developing a revenue stream for affiliated breeders since downstream restrictions on access to OSSI-Pledged varieties are prohibited. Largely for this reason, OSSI has not been appealing to breeders employed by public institutions or medium to large seed companies. OSSI is addressing the revenue issue by encouraging exclusive release and voluntary royalties. In Argentina, the most successful national seed company in the country has developed their own soya seed variety and their strategy is also to become first movers in the market, having dynamic catalogues with frequent updates and changes of available varieties on offer. This is proving an effective strategy to avoid being displaced by the multinationals this company competes with (Marin and Van Zwanenberg 2024). Bioleft's work is also enabling the commercialisation of OSS by creating collaborative business models for farmer-breeders and creating value-added products - such as OSS tomato pulp - and lobbying for the creation of policy regulations that support farmer breeders.

OpenSourceSeed has noticed that there are many plant breeders who reject IPRs, but so far only a few consider an OS protection against appropriation necessary. For many of the breeders they collaborate with, market access is more relevant than ownership demanding royalties. That is why OpenSourceSeed initiatives also aim to rethink the whole value chain and create cultivated diversity communities that include consumers. Plus, NGOs working with OSS and participatory breeding processes also require income to continue their work, and a value-chain approach can accommodate other stakeholders beyond breeders. In Germany, independent initiatives, such as urban nutrition councils, have emerged to carry out public engagement work, training and education on OSS. This has increased public awareness, demand and positive perception for OSS and the need for seeds as commons both nationally and in neighbouring countries. Reaching the public remains a main pillar of their work with the aim of building awareness and increasing consumer demand for food from OSS crops and foods.

In research and development, the German initiative has been analysing new mechanisms to finance OSS plant breeding (Kotschi et al. 2022). Research on finding alternative financing models suggests that OSS initiatives can be conducive to new funding mechanisms that can offer higher visibility of seed issues. They can also help enhance societal demand for stronger public breeding budgets that consider a wide range of growing conditions and methods. Evidence

suggests that current barriers for organic breeding, particularly for agroecological methods, are complex. The underlying issue is a lack of suitable public subsidies. 2013 data showed how 52 percent of organic cereal breeding in Germany and Switzerland was funded by NGOs, and only 12 percent was funded by royalties (Kotschi and Wirz 2015). Additionally, organic breeding still normally operates in a small cultivation area, thus lacking economies of scale. Furthermore, many organic breeders consider their cultivars as common good and reject IPRs (Deppe 2021). Overcoming these barriers requires a rethink to find allies in other links of the chain. Following the experience of Community-Supported Agriculture, we see that some OSS initiatives have already started to explore new financing avenues, e.g. involving citizens in new OSS value chains (Kotschi and Wirz 2015; Kasveista 2022; Colley et al. 2022; Kotschi et al. 2022); changing consumers' perception and awareness of breeding to create communities around seed; creating new models such as breeding cooperatives; or campaigning for the renewed investment programmes for public breeding (Kotschi et al. 2022). Overall, OSS is highlighting the need to incentivise breeders to test and adopt new financial models to fund their breeding work.

The OSS concept thus draws attention to the lack of research on alternative financial models for breeding for diversity. Plenty of participatory breeding projects and publications exist, but research on how to fund breeding for social and cultivated diversity lag behind. New projects such as LIVESEEDING, in which RSR participates, are looking at barriers and proposals to solve this issue (LIVESEEDING 2024). Emerging evidence suggests that the most promising alternative financial models include the involvement of diverse stakeholders in the value chain, creating demand for OSS foods, such as the bread, flour and pasta of the German and Italian cases; introducing a label for commons-based organic plant breeding, and establishing community-based plant breeding (Kotschi et al. 2022). A combination of approaches could become a powerful alternative strategy to significantly increase the overall budget for OSS agroecological plant breeding.

Conclusions

An entangled set of enclosures has resulted in a complex seed governance framework based on and fuelling the privatisation of plant genetic resources. Even many of the actors who built that framework acknowledge how the current overarching innovation and legal system for PGRFA requires urgent and radical transformation to ensure farmers' seed rights and the local stewardship of cultivated diversity.

OSS initiatives emerge in this rapidly changing context as an innovative solution that not only impedes processes of dispossession but can also facilitate the repossession of seed rights and breeders' freedom to operate while diffusing current lock-ins and path dependency in seed governance. This paper has presented empirical evidence of how OSS offers farmers and breeders committed to diversity, a safe legal space to reclaim seeds as common goods, using copyleft tools to turn them into *res communis*. This research has analysed the diverse applications of OS to seed in six different countries with very diverse policy and agronomic contexts across three dimensions: legal, knowledge and financial enclosures. These cases show how the OSS model cannot fully eliminate the chance of misappropriation of OSS varieties by powerful actors, but, first, it can diminish this risk; second, and more importantly, it can reduce the negative impacts of potential misappropriation by providing farmers and breeders using OSS varieties with the legal space to continue to use them, even if other actors attempt to enclose them. Thus, OSS emerges as an articulation of seed as commons, complementary to the ITPGRFA, creating a useful tool in the current governance framework, while wider gains for collective rights and freedom to operate continue to be fought for at the international level by many committed actors, including OSS groups.

OSS initiatives show that the OSS concept is used as more than a legal instrument, as it helps structure broad ambitions on systemic approaches to seed as commons: from participatory breeding, cultivated diversity through diverse populations beyond DUS varieties such as OHM, as well as new financial models for organic breeding, generating new frameworks for innovation in agriculture. OS encourages a broad conceptualisation of diversity not only for crops, but for the type of agroecological farmers and breeders who can take part and benefit from farmer-focused breeding, using different types of growing methods beyond intensive ones. These cases highlight the opportunity for the organic and agroecology movements to strengthen their work on seeds and breeding for diversity.

This paper has opened many questions and unexplored areas that the OS movement will have to consider as more OSS initiatives develop in different cultural and policy settings. These questions include: in reference to epistemology, for OSS models to have a wider benefit, more detailed assessments of the needs of farmers and breeders who operate in different formal and informal seed system realities will be essential. With regards to governance and policy, there is a core question on what policy and growing contexts will be more effective taking and defending a strong copyleft stance, and how OSS principles can better contribute to reinforcing farmers' seed rights and their participation in plant breeding as specified under the Treaty (e.g. Article 6

on Sustainable Use of Plant Genetic Resources). In the legal realm, many opportunities arise for exploring collective licences for varieties bred and stewarded by communities, as well as developing the compatibility and interoperability of licences and pledges across countries and policy contexts. Agronomically, as the climate crisis exacerbates extreme growing conditions and crop pests, research on crop diversity, such as OSS OHM, as well as on biosafety, seed-borne diseases and the spread of so-called alien species is becoming more urgent. These challenges trigger complex and stimulating questions around how OSS models can manage seed quality and make disease-resistant varieties more easily available. From a financial perspective, revenue channels for OSS farmers and breeders, and exploring new models for public breeding also require further research and policy will. With regards to digitalisation, the links between OS, DSI and democratic big data governance urgently need to be further developed.

In summary, the evidence and analysis presented show how OSS is emerging as a synergistic strategy full of potential to amplify seed rights through three dimensions: first, geographically, by connecting local and international efforts to enhance cultivated diversity and seed rights. Second, through a temporal dimension, by acting now within the current legal context, while contributing to the long-term transformation of seed governance. Third, through its capacity to be applied in both physical and digital realms, a key aspect in the era of DSI. We have argued how the notion of seed as *res communis* calls attention to the need for different kinds of institutions, logics, and ways of thinking and working with PGRFA. Further research is required to pave the way to recovering the human and cultivated diversity required to face the challenges ahead. Over 40 years of proposals for seed enclosures from the industry side - to capitalise on them - and from the civil society side - to protect them - have shown that seeds are hard to control. It makes environmental and social justice sense to return their status of common goods that do not need enclosing, but stewarding. OSS opens two connected pathways: to create commons and to protect the commons. The underlying social denominator to all OSS initiatives is working with communities of growers, farmer-breeders and citizens to not only free seeds, but free mindsets from the seed as *res propia* discourse into seed as *res communis*.

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Daniel Wanjama is the founder and coordinator of Seed Savers Network in Kenya. Daniel grew up in rural Kenya with his family practicing subsistence farming. First-hand experience with hunger motivated him to work in the civil service as an agricultural officer. However, he soon realised that the approaches and policies informed by the green revolution for the industrialisation of agriculture were not working for small-scale farmers. He noted that the increased use of hybrid seeds, fertilizers and pesticides was neither improving farmers' income nor enabling small-scale farmers to feed themselves with safe and sufficient food. In 2009, he founded Seed Savers Network to address food and nutritional insecurity, with seeds as an entry point. The network has now grown to the extent that farmers are conducting campaigns and reaching out to other smallholder farmers across the country.

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