



Perspective

The Use of Intellectual Property Systems in Plant Breeding for Ensuring Deployment of Good Agricultural Practices

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Abstract: Breeding innovations are relevant for sustainable agricultural development and food security, as new, resilient production systems require crop varieties optimally suited for these systems. In the societal debate around genetic engineering and other plant breeding innovations, ownership of patents on the technology used in the hands of large companies is often seen as a reason that small breeding companies are denied opportunities for further improving varieties or that farmers are restricted in using such varieties. However, intellectual property (IP) systems may also be used as tools to ensure the use of good agricultural practices when cultivating the resulting varieties. This paper explores documented cases in which IP systems (plant variety rights, patents and brand names) are used to promote that innovative varieties are grown according to good agricultural practices (GAP). These include effective disease resistance management regimes in innovative crop varieties of potato in order to prevent or delay pathogens from overcoming disease resistance genes, management regimes for transgenic insect-resistant Bt or herbicide-tolerant crops to prevent the development of resistant pests or weeds, respectively. The results are discussed with respect to the influence of breeders on GAP measures through various forms of IP and the contribution and role of other stakeholders, authorities and society at large in stimulating and ensuring the use of GAP.

Keywords: plant breeder's rights; patent; brand name; stewardship; resistance management



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1. Introduction

Plant breeding innovations are important for improving sustainability of agriculture and food production, as they speed up the process of making varieties that are suited for more sustainable agricultural systems, or they make it possible to breed them in a more precise way [1–3]. These innovations, or the crop varieties made with them, are subsequently protected by intellectual property (IP) rights so that the breeding company or entity that produced the variety may earn back the investment. This may be realized, for instance, by selling seeds of a variety or by licensing the propagation of the variety. For breeding programs that are not publicly funded, IP protection is generally considered to be indispensable.

In the societal debate around genetic engineering and other plant breeding innovations, IP systems such as patents are often perceived as hindering innovation because the access to plant genetic resources may be reduced, particularly for small breeding companies, or the access to varieties may be restricted for farmers. On the other hand, these systems may also be tools to ensure the use of good agricultural practices (GAP) when cultivating innovative varieties. We elaborate on the latter notion here.

This paper starts with an introduction of various IP systems that may be used by plant breeders. We then go on to describe the opportunities that patents, plant breeder's rights and other IP systems, as well as related contractual obligations, may offer for introducing and ensuring GAP stewardship schemes. We describe examples of effective integrated resistance management (IRM) regimes that need to be implemented in order to

prevent or delay pathogens, pests or weeds from overcoming valuable resistance genes in new varieties, as single (dominant)-resistance genes in particular are prone to being overcome by the continuous evolution of pathogens, whether they were introduced through classical introgression breeding or by modern biotechnological methods. We then explore documented cases with a longer history of cultivation (e.g., transgenic insect resistant (IR) Bt crops), where good resistance management was found to be of the utmost importance with regard to GAP, and other cases, including the management of disease resistances in potato. In some of these cases, the obligations to ensure good resistance management were mandated by competent authorities to breeders, who used licensing contracts to ensure compliance by farmers. In other cases, it was driven by the desire to employ IRM to maintain the functionality of the disease-resistant genes. The gained insights will be discussed with respect to possible pros and cons from the points of view of the breeders, farmers and society in general.

2. IP Protection for Plant Varieties

In this section, we briefly discuss four IP systems that appear to be most relevant to ensuring GAP. Additional forms of IP protection exist, such as trade secrets and geographical indications, but these will not be discussed in this study. First, the IP system most utilized globally for the protection of plant varieties is the plant breeders' rights (PBR, also called plant variety protection (PVP)) system. PBR is a dedicated system for plant and mushroom varieties based on the International Convention for the Protection of New Varieties of Plants. It is administered by the International Union for the Protection of New Varieties of Plants (UPOV), an intergovernmental organization with headquarters in Geneva (Switzerland). As long as a variety is distinct (from all others), uniform (among plants) and stable (across years) (the so-called D.U.S. characteristics), the breeder will be granted plant breeders' rights. The level of protection is predefined. For a period of 20 or 25 years, the breeder has the exclusive rights to give licenses to others to multiply or use the variety and to charge a license fee on the multiplications or use of the variety for agricultural production. The breeder only obtains rights on the combination of traits (genes) that is unique for this variety and not on the underlying genetic material, which remains available for crossing and selection (the "breeder's exemption" [4]). As a result, the variety can freely be used for breeding new varieties by anyone from the first day that it is on the market. There are also exemptions for farm-saved seeds (the "farmer's exemption"), the details of which vary across jurisdictions. The US provides for the PVP system, and in addition, since 1930, it has had a similar type of protection for new varieties of non-tuberos, asexually propagated species, perhaps confusingly termed a "plant patent". Further reading on the PBR system may be found in Würtenberger et al. [4].

Second, the generic IP system of patents may be applied, as it is open to any industrial application that is novel and has an inventive step. Utility patents are granted on a country basis or on a regional basis, and the exact scope and conditions for granting these may vary between jurisdictions. In Europe, patent applications are assessed and granted by the European Patent Organization (EPO), which is an organization with 38 member states based on the European Patent Convention. The EPO is separate from the EU [5]. A patent gives control of the use of the inventive application that it describes. The type of applications and the level of protection can be formulated precisely in the claims, tailored to the invention that is to be protected. As a result, it enables tight control of the application once a patent has been granted. A "patent on a gene" thus does not give ownership of the gene (the gene already existed in nature before a patent was granted and continues to do so), but it restricts its use for specified applications.

Patent law and PBR are separate systems for IP protection, and they operate independently from each other. According to the European Patent Convention (EPC), a plant variety as such cannot be patented. In addition, methods involving classical crossing and selection are exempted from patentability, as they are processes of an "essentially biological nature" (Article 53(b) EPC and Article 4(1)b in the EU Directive on legal protection of

biotechnological inventions 98/44/EC) [5]. With technical developments such as the use of DNA markers in plant selection, “natural” traits became a subject of patent applications, leading to discussions about the interpretation of the exemption for processes of an “essentially biological nature”. Patents on the use of spontaneous variants of genes or natural traits in plants may be employed to indirectly control all activities with varieties in which the traits are used, including crossing with them and further breeding, and thus they may restrict the use of genetic resources for plant breeding. This has triggered a lot of debate and led to calls from, among others, the European Parliament (“stop patents on life”).

In the context of this study, we can only briefly discuss the outcomes of this complex debate. The notion of technical steps making processes of crossing and selection eligible for patenting was refuted during procedures at the Enlarged Board of Appeal (EBA) of the EPO, but in the 2015 rulings on the so-called “Broccoli II” and “tomato II” cases, G 2/12 and G 2/13, respectively, the EBA concluded that this non-patentability did not extend to the plant products from such processes. Following extensive discussions, in a follow-up case on pepper (G 3/19, <https://www.epo.org/law-practice/case-law-appeals/communications/2020/20200514.html>, accessed on 1 June 2021), the EBA recently (2020) decided to stop issuing patents on naturally occurring (“native”) traits and on the plants containing them. In other jurisdictions, particularly in the US, patenting is still more widely possible on plant traits. Notwithstanding the exclusion of natural traits, the application of targeted technological methods to change genomes may still be patented, including transgenics.

Patents on transgenic constructs have been used to earn back large investments and make profits for breeders and technology providers. Other players in the production chain also benefit from improved varieties through higher efficiency and yields of cultivation or products with better quality/price ratios. The extent to which patents impact on the redistribution of welfare gains depends on the crop species, GM trait, region and socioeconomic context [6–8]. Patent protection may also apply to varieties made with cisgenics and gene editing using CRISPR/Cas, as these would entail targeted changes in genomes. These technologies are not necessarily regarded as “essentially biological processes” in the European context, even though the products may be essentially similar to those from conventional breeding. European farmers have already initiated a dialogue focused on disallowing the issuance of patents on transgene-free, gene-edited crops (Institute on Science for Global Policy [9], pp. 40–41).

Third, a mechanism for control that is gaining traction is based on ownership of a brand name. A plant variety that is traded must be identified by its official name. This helps the owner to trace the use of its variety, but the official name under which the variety is listed is not a protected item in itself. As a consequence, after the breeders’ rights have expired, anybody may multiply and sell the variety under its original name. Essentially derived or similar varieties being sold under that name is common practice in fruits such as apples, where “sport” varieties exist which are distinguished from the original variety by a spontaneous mutation. For example, a series of apple sport varieties with a more intense color or a shinier look are sold in shops under the name of the original variety: Elstar. Under EU trademark law, already-registered variety denominations cannot be applied for as trademarks. One way to exercise control is to register a trademark for a separate brand name and then link that protected brand name to the PBR-protected variety. The owner can then regulate the conditions under which it is allowed to sell the variety under the brand name. An example of this is Pink Lady[®], which is a trademark for apples of the Cripps Pink variety. These apples may only be sold under the brand name Pink Lady by authorization of the owner, who has, for example, standardized the cartons in which they are sold [10]. Other attributes are currently being attached to the brand name, including sustainable cultivation practices. One advantage compared with PBR is that a brand name or a trademark does not expire. The downside is that there are costs for maintaining protection on two items rather than one.

Fourth, a general way of guarding the use of a variety or of plant material is through legal contracts under private law, as one may always arrange a legally binding agreement

between two parties. These may comprise obligations to implement GAP, including the right of the owner of the variety to check this on the farmer's fields. Contracts may also take the form of contract cultivation, where the breeder or owner hires farmers to grow or multiply the variety, the farmer delivers the harvested product to the owner, and the farmer gets paid for his or her cultivation efforts, taking into account the GAP measures.

GAP may also be enforced in other ways, such as by public law rulings [11]. Examples from the Netherlands include the obligation to control potato volunteers to avoid the spread of plant diseases (e.g., *Phytophthora infestans*) and pests (e.g., the Colorado beetle) and the obligation to control bolters in sugar beet to prevent, among other things, virus spread (beet yellowing virus). These were originally enforced by commodity boards. These systems fall outside the scope of our overview.

3. Examples of Ensuring GAP

3.1. Resistance Management for Bt Crops

In the US, the Environmental Protection Agency (EPA) mandates IRM for insect-resistant Bt crop registrations, which are issued for limited periods. This has been the case since the introduction of Bt crops in 1996, upon the expression of concerns by scientists [12]. The EPA obliged planting parts of fields with non-Bt crops, and after 2010, they also allowed the use of sowing seed mixtures of Bt and non-Bt seeds (refuges "within-a-bag") to make compliance easier for farmers. Stewardship and post-market environmental monitoring (PMEM) at the authorization of Bt is also obliged by the European Food Safety Authority (EFSA) in the EU and by the Canadian Food Inspection Agency (CFIA) in Canada [8]. In Australia, the authorization by the Office of the Gene Technology Regulator (OGTR) of a GM crop may include licensing conditions for the registering breeding company. The breeding company (registrant) performs audits of compliance to plans that are obliged in (licensing) contracts arranged by the technology provider with the growers. The provider is responsible for reporting compliance and monitoring and mitigating pest resistance risks with guidance by Transgenic & Insect Management Strategies, a commission of stakeholder experts, to the Australian Pesticides and Veterinary Medicines Authority (APVMA) [13].

Through the patents on the Bt events, the breeders or technology providers are in a position to arrange for stewardship schemes through licensing to the providers of sowing seeds and to farmers. To ensure compliance by farmers, licensing contracts include obligatory monitoring and reporting to the regulatory agencies, and deliveries to non-complying growers may be canceled. The limitation of a patent to a duration of 20 years could, in theory, negatively affect the breeding companies' interest in preserving crop varieties that only contain genes or events for which the patent has lapsed. In practice, however, upon problems with resistance development in insects, breeding companies develop and release alternatives, often varieties with stacked variants of Bt (in which Cry genes are pyramided) [13].

The extensive review by Carrière et al. [13] discussed incentives for resistance management and showed various levels of success with promoting stewardship with Bt crop cultivation. Their comprehensive review did not state the aspect of licensing explicitly as an advantage of patents on the crops, but it discussed licensing in light of the obligations mandated by competent authorities. It also touched upon tensions with free market competition. In the USA, cross-company compliance data are compiled (e.g., through the Agricultural Biotechnology Stewardship Technical Committee (ABSTC)) and released publicly (e.g., through the National Corn Growers Association), but individual technology providers do not disclose the level of compliance for reasons of market competition [13]. Farmers who are denied Bt seed because of non-compliance by one technology provider can still purchase Bt seed from competitors.

Durable resistances can be seen as a so-called common pool resource, as resistance management will often not be directly profitable for farmers. Occasionally, "resistance crises" have made farmers acutely aware of the risks of short-term economic incentives, and these generally have also helped to act in voluntary enlightened self-interest, provided

that their peers are acting in the same way [13]. Next to this, making subsidies conditional on IRM may support compliance, pointing to a role of regulatory actions by government agencies. Promoting stewardship through companies' IP usually occurs in interaction with the actions of competent authorities. The details of the flanking actions vary among countries, and this may have contributed to different levels of success. For instance, in the US, the ABSTC was facilitated in coordinating IRM by consolidation of the breeding industry. In Australia, the government had a strong incentive to act due to a previous "insecticide resistance" crisis with *Helicoverpa armigera* (a caterpillar that is also targeted by Bt). Here, competent authorities have prioritized approaches through farmer organizations. Cotton grower organizations support research programs funded by a levy to growers, which is matched by the government, and actively promote the implementation of IRM strategies. In South Africa, a monopoly of a single provider at the introduction of Bt maize did not prevent the first, relatively fast resistance development against Bt in the maize stem borer *Busseola fusca* [13], for which refuge compliance was initially low [14].

Despite all the arrangements discussed above, compliance is poor in many regions of the US, which is accompanied with resistance problems [13]. In other countries with less tight control from competent authorities via contract relationships between providers and growers, IRM also appears to be less successful. In Brazil, the Brazilian National Biosafety Commission (CTNBio) does not enforce IRM with Bt crop authorization. Although stakeholders, including technology providers, do actively promote IRM and monitor resistance development, more strongly so with resistance development occurring in *Spodoptera frugiperda* and *H. armigera*, compliance still appears to be quite low, perhaps only at a rate of 20%. In India, the Genetic Engineering Appraisal Committee (GEAC) mandates monitoring and refuge planting with the authorization of Bt crops. Refuge cotton or pigeon pea are provided by seed companies, but registrants are not obliged to report on compliance. Nevertheless, particularly for the many smallholders, who often have little education in IRM, it is not economically feasible to plant refuges. They may also obtain seed from unauthorized sellers. After a "resistance crisis" with cotton bollworm, the government has promoted education, and since 2018, seed mixtures, including varieties with pyramids of Bt genes, have also become available. As an alternative for addressing cost limitations, communal refuges were suggested as a possible solution by Carrière et al. [13]. Thus, from this Bt case, we can conclude that patents facilitated licensing to grow Bt crops under GAP. However, supporting policies (regulation, subsidies and education) are required to ensure reaching successful IRM in the long term.

3.2. Late Blight Resistance Management in Potatoes

Late blight-resistant potatoes contain specific disease resistance (R) genes, which have been introduced by introgression breeding or by transformation (cisgenesis). The causative pathogen, the oomycete *P. infestans*, is notoriously fast in overcoming single gene-based resistance. Therefore, pyramiding of multiple resistance genes in a potato variety prior to release and careful monitoring of resistance development in the pathogen on a (semi)permanent basis during cultivation are essential, and this should be supplemented with a protective fungicide application whenever a resistance gene is in danger of being broken [15]. Even when taking into account the possible need to occasionally protect the resistance gene with fungicide applications, the cultivation of resistant varieties is expected to lead to 75% lower fungicide usage [16].

In the DuRPh (Durable Resistance against *Phytophthora*) project, a cisgenic late blight-resistant potato was developed [11,16,17]. This cisgenic potato was produced by stacking resistance genes against *P. infestans* that were obtained from the gene pool of species of the *Solanum* genus that are cross-compatible with the cultivated potato *Solanum tuberosum* [16]. Growers of the late blight-resistant variety would apply fungicide as advised by a decision support system, overall enabling potato growers to sustain late blight resistance with as little use of fungicide as possible for a prolonged period of time [15]. This is a form of IRM. Important to such arrangements are accompanying incentives for breeders to

stack resistance genes in their varieties and for growers to bear extra efforts from resistance support systems. Patent applications were submitted for the resistance genes in order to be able to control who could receive licenses and how they were going to be used. Patent licensing of the resistance genes can thus be a tool to stimulate breeders to develop varieties with stacked resistance genes instead of single-gene constructs and, as a next step, like in the Bt cases, to oblige farmers to employ IRM and use the aforementioned decision support systems. Until now, there have not been applications for the authorization of cisgenic potato varieties within the EU due to the current registration hurdles [15,18]. Cisgenic late blight-resistant varieties are also being developed in the US, where (in contrast to what one may expect from an optimal IRM system) variants with a single gene have been authorized, but stacks of three genes are expected by 2025 (<https://spudman.com/article/biotech-potatoes-improved-performance-quality-global-markets/>, accessed on 1 June 2021). As with Bt crops, EPA approval of the single-resistant varieties for cultivation encompassed an obligatory stewardship program, including recommendations of protective fungicide treatment to support the durability of the resistance and obligations for reporting and monitoring in the form of assessing unexpected damage cases (UXDs).

Thus, IRM should start with stacking resistance genes, which may be required through conditional licensing of the patents on the resistance gene constructs, to create varieties with potentially durable disease resistance. The proper implementation of IRM during cultivation of resistant varieties should be ensured through additional license agreements. This way of using IP protection was considered as a potential advantage in an extensive stakeholder interaction and public debate that was organized around the DuRPh project [11,17].

Another way of protecting the use of a variety or of plant material is through legal contracts under private law. As stacked late blight-resistance gene potato varieties are still in the pipeline of classical introgression breeding, stewardship arrangements focus on sustaining the potato varieties with single resistance genes that are not yet broken (as in the US cisgenic example above). Farmers that cultivate the single resistance cv. Avito in the form of contract cultivation are obliged by the owner of this classically bred variety to apply fungicide when advised to do so by a decision support system in order to prevent breaking the resistance by *P. infestans*. In this system, fungicide spraying is much lower than with susceptible varieties (spraying is needed, on average, 4 times instead of 15 times per growing season), compensating for the higher cost of the seed potatoes. Compliance is monitored, and its success is rated by the absence of *P. infestans* in the crop [11].

3.3. *Bremia* Resistance Management in Lettuce

In a recent expert workshop, downy mildew ranked seventh on a list of most urgent needs in the EU for developing biocontrol options and integrated pest management [19]. In the Netherlands, *Bremia lactucae* is a worrisome oomycete disease in lettuce. Although there is an incentive for stewardship in light of the steady decrease in fungicides registered for use in the EU, there is limited use of integrated pest management because of uncertainty about its (economic) effectiveness and a lack of knowledge, according to a recent monitoring report for the Netherlands [20]. For cultivation of varieties with conventionally introgressed resistance genes against this pathogen, fungicide application to prevent breakage of the resistance gene by the pathogen is being advised. Breeders are monitoring the development of new pathotypes breaking resistances, and data are being collected by the International *Bremia* Evaluation Board, a collaboration of breeding companies in the USA and Europe with UC Davis, the Netherlands' inspection service Naktuinbouw and the French National Seed Station GEVES (IBEB; <https://www.worldseed.org/our-work/plant-health/other-initiatives/ibeb/>, accessed on 1 June 2021) [21]. Information on resistances and *Bremia* isolates are used in protocols for DUS testing in variety registration. Implementing IP for ensuring GAP in Europe with conventionally introgressed resistances would need to be based on PBR, but this may not be straightforward, and there are apparently no examples in literature of how PBR could be used in this manner (for more, see Section 4).

3.4. Management of Herbicide-Resistant Crops

In Australia, glyphosate-resistant weeds developed because of glyphosate use prior to the introduction of herbicide-tolerant (HT) transgenic crops. As glyphosate is the herbicide used for the most common transgenic form of HT crops (Roundup Ready (RR)), a resistance management plan became an obligation at the Australian Pesticides and Veterinary Medicines Authority (APVMA) that oversaw the registration of agricultural chemicals. Thus, the obligation was not linked to a particular HT crop but to the authorization of the herbicide used in its cultivation in Australia and, thus, to the herbicide registrant. The IP for glyphosate (Roundup®) was originally granted to the same company as for the HT (Roundup Ready®) crop. Nevertheless, the obligation to follow APVMA rules was subsequently included in the authorizations of GM HT crops by the OGTR. Analogous to the plan described for Bt crops above, the IRM plan includes reporting of resistance incidents and establishing an herbicide resistance consultation group (i.e., the Glyphosate Sustainability Working Group), consisting of experts, industry and government (extension) officials [22]. For instance, glyphosate-resistant cotton cultivation is regulated by a crop management plan which imposes an obligation to prevent seed sets of weeds that have survived glyphosate treatments, even though this may be difficult to realize in practice [23].

In contrast, the US had no strict, obligatory stewardship scheme against resistance development as, originally, resistance development was regarded as unlikely among others, based on experience with selecting for plant 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) resistant to glyphosate [24]. From an evolutionary view on weed control, this unlikelihood was seen as doubtful [25], and indeed, over time, resistance development to glyphosate has occurred. Some of the resistances developed on the basis of previously unknown genetic mechanisms such as gene copy multiplication (involving extrachromosomal circular DNA), and these led to seriously problematic weeds including Palmer amaranth [26]. Breeding companies have reacted with the development of (stacked) HT crops involving herbicides with alternative modes of action, similar to the Bt-pyramided varieties described above in Section 3.1. Increasingly, stewardship schemes are now promoted with advice for sustainable management by organizations such as the Weed Science Society of America.

There have been worries that, with an emphasis on HT crop solutions, less attention may be given to developing innovative, alternative agronomic measures for integrated weed management (IWM) [25,27]. IWM involves more complex cultivation practices and requires frequent monitoring, as is performed in organic cultivation. It requires more knowledge development of farmers and still has a higher risk of crop failure [28]. Cultivation of HT crops within an IWM system approach could have formed a good case to prevent or delay the development of herbicide resistance in weeds, but the perceived difficulty of implementation due to the inherent complexities and risks of failure for growers may have been reasons to not demand this. Considering the experiences in Australia, including with Bt as described above in Section 3.1, accompanying HT crops with contractual obligations for IWM would require the establishment of working groups involving grower organizations to ascertain IWM's feasibility for farmers. With hindsight, it may be a lost opportunity that authorizations for HT crops in the US were not accompanied with stewardship obligations for IWM, which could have been ensured through licensing contracts by the technology provider, as were implemented for Bt crops or late blight-resistant potatoes (Section 3.2).

3.5. Scab Resistance in Apples

An example of using trademarks is the Dutch apple variety SQ159. As it is resistant against apple scab, it fits well in organic as well as conventional production. The trade name Natyra® is reserved for apples of this variety that have been produced organically. Conventionally produced apples are sold under other trade names. The pathogen *Venturia inaequalis* has a sexual cycle during the winter months (production of ascospores on fallen leaves) but propagates clonally during the rest of the year through conidiospores. Hence,

resistance management includes keeping the orchard clean and removing dead leaves in the fall, which is common practice. A round of preventive spraying with a fungicide at the beginning of the growing season is advisable to restrict the development of new apple scab strains. Including this in licensing contracts for growers of a sustainable brand of scab-resistant apples would be an opportunity for promoting IRM.

4. Discussion

Society demands new, resilient and sustainable production systems. These will require crop varieties optimally suited for these systems. The intrinsic properties of a variety, however, do not automatically translate into differences in sustainability performance during cultivation. The environmental effect of varieties critically depends on them being cultivated according to good agricultural practices (GAP), as was shown for GM crops with specific added traits [6–8]. The impact of conventional varieties similarly depends on the application of GAP during cultivation, as this contributes to many aspects of sustainable farming, including integrated control of weeds, diseases and pests and the optimization of fertilization and irrigation [11]. For that reason, breeders may be interested in directing GAP for the cultivation of their varieties, such as when these varieties contain disease resistance genes that have been recently introgressed from wild relatives which, in crops with complex genetics, may take longer than the pathogen may need to break it. Specifically, the durability of the resistances requires proper disease management to maintain the effectiveness of the resistance genes in their varieties over time. In the case of GM varieties, such as Bt crops, several governments (competent authorities) have obliged breeders to ensure specific cultivation measures.

To be able to ensure measures further down the production chain, one needs instruments for controlling the use of a variety. Licensing contracts based on patents are a versatile instrument for enforcing integrated resistance management (IRM), such as by providing the owner of a transgenic event with the capability to pass on obligations to the breeders of all varieties, in which the event is implemented or stacked, and from here to the sublicensees and farmers. Licensing contracts have been used for ensuring compliance to the GAP demands for varieties with Bt constructs. They were aimed to be used for developing potato varieties made with disease resistance genes in the DuRPh project.

There may be conflicting interests between the company that sells a variety with accompanying GAP obligations and the farmers that buy it. In a free market, farmers may opt for another seed provider. In the case of GAP obligations, farmers may also be inclined to do so not only when being excluded because of poor compliance, but particularly when compliance is disadvantageous because of the costs involved [13]. Part of the solution may lie in providing alternative approaches that are technically easier to implement. For example, farmers can now buy Bt varieties as seed bags in which Bt and non-Bt varieties are mixed, thus eliminating the need to set up and cultivate a separate refugium, even though the latter may be more effective in terms of disease resistance management [13]. The examples of problems with compliance suggest that success in ensuring the implementation of GAP measures may critically rely on the involvement of all stakeholders in the production chain, not only breeders, but also competent authorities and farmer organizations. An essential component, next to appropriate regulatory arrangements that independently check for compliance, may be strong involvement of farmer organizations, extension services and product market chain parties, providing education programs to farmers and making available digitalized decision support systems. This is particularly true in cases where GAP involves complex operations that may come with higher costs or risks of failure or that require sophisticated knowledge and experience for farmers, as was noted for weed management with HT crops.

Closed production chains and contract cultivation, such as the potato cv. Avito example, form an alternative system to ensure compliance to GAP measures. As farmers are contracted, the company that gives out the contracts remains in the lead throughout the cultivation cycle. One may consider it a disadvantage that this restricts the role of farmers

to mere executors of instructions. On the other hand, the parties in the production chain now have a joint interest, and for that reason, the company may actively assist farmers that have been contracted with education or practical support, such as the decision support system for *P. infestans* in potato.

Plant variety rights can only be exerted on a plant or a product until the full license has been paid, which limits the options of the owner to direct GAP measures during cultivation. For a breeder, the possibilities of control of the application of GAP using PBR may be larger for vegetatively produced varieties than for varieties that are sold as sowing seeds, as the period of control may be extended by breaking up the license into portions. During multiplication (e.g., of fruit trees), the number of licenses may be limited, and this may be used to enforce the use of certain cultivation measures.

The role of the owner of the PBR may be extended by combining it with special production chains for products with added value in terms of quality or other production characteristics. This may be done by teaming up with others, both vertically in the production chain, such as trading organizations, or horizontally, such as by geographical indications. The breeder may strengthen his or her position by linking the variety (indirectly) to a brand mark or a trade name, as is done now for some new apple varieties. A brand name may be associated with the use of cultivation practices, and the brand can enforce them with growers if they want their product to be sold under the brand name.

There may be limitations to using IP systems for ensuring GAP. Patents concern a technical invention that is applicable and novel. In the future, it may become more difficult to obtain a patent on the use of a disease resistance gene, such as on the resistance gene R8 in the DuRPh varieties, as the novelty of the application of resistance genes gradually decreases over time with an increase in the number of scientific publications on disease resistance genes in plants. GM events are usually novel combinations of genetic elements, and for that reason, they are expected to remain patentable. The patentability of gene-edited changes can be expected to be the subject of legal as well as political debates in the coming years, particularly when they result in plants similar to those from conventional breeding, as may be the outcome of targeted mutagenesis when it is used to induce one or more small deletions in genes [29,30].

Thus, while the application of good agricultural practices (GAP) during cultivation is an essential factor for the effectiveness of novel varieties for improving the sustainability of farming, the power of the breeder to ensure this in the production chain using IPR varies depending on the type of trait, the type of crop, the IP system chosen and the characteristics of the production chain. Several of the examples described here point not just to the important role of the government, but also of grower organizations and market chain parties. By means of adopted and agreed farming decision support systems, farmers can be guided and assisted in their compliance to and implementation of GAP. The use of decision support systems may be stimulated, for example, by making subsidies or purchases conditional on this compliance. The resulting stewardship roles of parties that have a joint interest in producing food according to GAP should complement the actions of the breeders.

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