A breeding consortium to realize the potential of hybrid diploid potato for food security

Hybrid diploid breeding is a radical innovation that promises to revolutionize breeding practices in potato, the world's third-largest food crop. Yet concerted efforts are needed to ensure this innovation can be harnessed for food security.

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Potato (*Solanum tuberosum* L.) is the world's third most important food crop, after wheat and rice, and its importance to the global food supply is expected to increase thanks to its relatively low water need, easy cultivation, and healthful nutrient content. To fully realize its potential for food security, however, potato varieties need to be adapted to the needs of the many smallholder farmers in this world, primarily by reducing potato's susceptibility to pests and disease, and by increasing its adaptability to climate change[1].

Conventional breeding practices have achieved only limited success in reaching these goals, partly because potato's complex tetraploid genome makes it challenging and time-consuming to introduce new traits—a process that can take many decades to succeed. Recently, hybrid diploid breeding has emerged as a radical new method in potato breeding that promises much greater success in unlocking potato's huge genetic diversity. In 2011, researchers from a Dutch start-up company published on the development of a (non-GMO) method to overcome the self-incompatibility of diploid potato, which had previously prevented the crucial step in hybrid breeding to create homozygous parental lines through inbreeding[2,3].

The use of self-compatible diploid potatoes opens up the possibility of creating a hybrid potato breeding system, which can drastically cut the time required for developing new varieties, make it easier to incorporate and combine new traits that are available in germplasm collections, and allow potato to be grown from easily transportable true seed instead of bulky tubers. Hybrid diploid breeding thereby enables potato genetic resources to be unlocked with greater speed and precision compared to conventional breeding, and can thus offer tremendous benefits to smallholder farmers facing food insecurity.

Accessibility not guaranteed

To realize this promise, it is crucial that hybrid diploid breeding be made widely accessible[4]. This is currently not the case, however, because the inbred parental lines on which hybrid breeding crucially depends are falling through the cracks of the institutional arrangements that are supposed to ensure the wide accessibility of breeding materials and genetic resources.

In the recent past various institutional arrangements have been created to ensure the accessibility (and conservation) of plant genetic resources. The international system of breeding rights under the International Union for the Protection of New Varieties of Plants (UPOV) ensures the accessibility of new varieties for further breeding purposes. Under the International Treaty on Plant Genetic Resources for Food and Agriculture (PGRFA), fair and equitable sharing of the benefits of genetic resources has been secured. A global network of gene banks maintains large collections of germplasm, and various informal practices have emerged among breeders to exchange genetic material even before breeders' rights have been obtained[4,5].

However, neither breeders' rights or patent law, nor the various international treaties and practices for sharing genetic material, generally apply to inbred parental lines as the vital ingredient in hybrid breeding. Homozygous parental lines enable new traits to be incorporated in potato varieties at unprecedented speed, as is evidenced by the recent development of a double-stacked phytophthora-resistant variety in less than two years[6]. Developing these lines is a protracted, burdensome and expensive process, requiring breeders to overcome several challenges associated with the inbreeding process, such as the lack of vigor and difficulties maintaining male fertility[7,8]. In the absence of institutional incentives or requirements to share (and safeguard) these parental lines, breeders mainly have resorted to secrecy to protect their investments. As a result, access to potato parental lines is restricted to firms or public research institutions that are willing and able to make long-term investments in a hybrid breeding program.

What to expect from the private sector?

The limited accessibility of parental lines as a basis for hybrid potato breeding constrains the potential contribution of this innovation to global food security. Currently these lines are almost exclusively being developed by a small number of private companies. In China and the United States hybrid potato breeding has also been taken up by public research institutes, but this publicly funded research focuses mainly on the genetic basis of hybrid breeding[8]. Moreover, public sector breeding institutions, like the international CGIAR centers and national agricultural research institutes, are mostly project-funded research organizations, without the capacity to develop full-fledged hybrid breeding programs.

By producing high-quality hybrids, private companies seek to open new markets for true potato seed, also offering the promise to contribute to global food security. The Solynta company, which has pioneered hybrid diploid potato breeding, indeed cites this as an important objective and has already undertaken several field trials with hybrid varieties in different African countries[9]. However, the question of how to combine business opportunities with variety development that serves smallholder farmers and global food security is widely seen as a major challenge. This is what we learned from our interviews with several dozen scientists, government officials and companies, and it is also confirmed by the results of an international workshop and conference on 'potato futures' that we helped to organize[10,11].

In principle, hybrid diploid breeding offers a unique opportunity to develop potato varieties that are resistant to pests and diseases that predominantly occur in developing countries, like bacterial wilt and various viruses[12,13], or to develop varieties that can thrive in tropical lowlands or under erratic and changing climate conditions. However, for private companies, resource-poor smallholder farmers do not constitute a sufficiently profitable market, among other things

because in low-income regions it will be difficult to create dedicated hybrid potato value chains and farmers generally only buy high-quality seed once and then replant the tubers in subsequent seasons.

A special and highly successful counterexample is East-West Seed, a commercial breeder of vegetable hybrids in tropical countries that has succeeded in placing the needs of smallholders at the heart of its business. In general, however, the focus on commercialization and profit-seeking inherently favors the development of varieties that can be sold in the highest quantities or at the highest price—conditions that do not really align with the specific needs of smallholder farmers. This is also confirmed in the literature on potato cultivation in Africa, which clearly shows that innovative seed technologies often do not fit poor farmers' realities[14,15].

Thus, to fully reap the benefits for food security, we cannot leave the new method of hybrid potato breeding to private companies alone: we need to make this innovation available and accessible to public breeding organizations as well. Indeed, public breeding organizations can intentionally allocate scarce genetic resources among farmers working in small and exceptional adaptation areas who are unlikely to be served by the private sector[16].

Hybrid breeding consortium

How can hybrid potato breeding be made more accessible? We know that transformative innovations can either alleviate or increase inequality, depending on their accessibility. These implications for inequality are usually addressed by institutional arrangements that ensure access to the products of innovation—for example, by granting patent exemptions for essential medicines or private agreements to make genetically modified crops available at lower prices in the global South. Yet such institutional arrangements only intervene after a commercial product has been developed, whereas with hybrid breeding the limited accessibility of parental lines may prevent urgently needed products from being developed in the first place.

What is needed instead is an institutional intervention that helps to change the direction of technological innovation itself. We therefore propose the establishment of a consortium for hybrid potato breeding, in which public breeding institutions, the private sector and farmers collaborate in hybrid breeding efforts that are exclusively aimed at smallholder farmers. An essential feature of this consortium are partnerships that strengthen the role of public breeding institutions with the aims of serving food security as a major sustainable development goal, of stimulating the private sector to fulfill its mandate of corporate social responsibility, and of creating incentives for farmers to share in situ genetic resources[17].

The consortium that we propose may be established on different partnership models. Private breeding companies may participate in the consortium by sharing their potato parental lines, thus making available these lines to the participating public institutions, which can further improve and use them for hybrid variety development serving the needs of smallholder farmers. Alternatively, public breeding institutions participating in the consortium may direct the generation and selection of hybrid cultivars for the needs of resource-poor farmers by obtaining hybrid seeds from a dedicated program of crosses between potato parental lines, carried out by the participating private companies owning these lines.

Benefit sharing as basic principle

We propose 'benefit sharing' as the basic principle for the establishment of this consortium. In a partnership model with private companies sharing their potato parental lines, the participating companies may be allowed to market hybrid varieties acquired from the public breeding institutions while the breeding consortium ensures the accessibility of hybrid planting material exclusively for smallholder farmers not involved in formal markets. In a partnership model with public breeding institutions obtaining hybrid seeds from participating private companies, these companies would be free to market these seeds while waiving their breeding rights for hybrid planting material that is made accessible by the breeding consortium exclusively for smallholder farmers not involved in formal markets.

The partnership models established by the consortium that we propose do not replace but complement private breeding efforts, with little to no additional investment from the private sector, while companies may benefit in case of public breeding success. We further propose to closely involve smallholders farmers in the development of new varieties. By incorporating the knowledge, needs and concerns of smallholder farmers, the consortium ensures that hybrid breeding efforts meet the complex and diverse realities of these farmers[18]. This mirrors the recent call for an innovation systems approach in which farmers are considered as partners in the innovation process, instead of passive adopters of knowledge and technologies[19,20]. What we have in mind goes beyond the methods frequently used in the private sector, such as demonstration trials and willingness to pay approaches, and aims to involve smallholder farmers more closely in the breeding process, making variety development more responsive to their circumstances and needs[21].

For now, the experiences with hybrid participatory breeding of maize can serve as an example[22,23]. In this case, public sector breeders recognized that locally adapted landraces and farmer-improved maize varieties were a promising base for further hybrid improvement. By close collaboration with the local farmers, the breeders were able to understand the complex agroecological and socioeconomic conditions under which farmers had to work. Considering the farmers' trait and landrace preferences, the breeders started a program of hybrid breeding whereby farmers were invited to evaluate and select their most preferred crosses. Under an access and benefit sharing agreement, the breeders shared with the farmers the final selected seeds and inbred lines for community seed production, while the seeds were also certified and released for wider exploitation by a commercial seed company.

An added benefit of participatory breeding is that a consortium that is dedicated to the needs of smallholder farmers may offer new incentives for farmers in potato centers of origin to share in situ genetic resources, which have become increasingly difficult to access[17]. This may broaden the genetic base of hybrid potato breeding and thereby strengthen its potential contribution to food security[24].

We believe that a breeding consortium can indeed maximize the potential of hybrid potato breeding for food security, but only if certain conditions are met. The parental lines shared by private companies in the consortium should be treated confidentially. The public use of these parental lines or hybrid seeds obtained from these companies should be restricted to the development of varieties that are exclusively aimed at underserved smallholder farmers. And the consortium should be placed under the aegis of an organization with sufficient expertise in potato breeding for food security, such as the International Potato Centre in the global CGIAR network.

Recommendation

Hybrid diploid breeding offers a unique opportunity to catalyze potato's contribution to global food security. However, the lack of institutional incentives to share inbred parental lines suppresses efforts to use this innovation for the benefit of smallholder farmers. We argue that a hybrid breeding consortium can offer a solution. While

radical, our proposal is not entirely without precedent. The call to create partnerships based on benefit sharing resonates with an earlier statement of public and private sector potato scientists, with the suggestion to dedicate some programs, perhaps government programs and/or private companies, entirely to developing the diploid system[7]. Furthermore, despite the veil of secrecy that otherwise surrounds inbred parental lines, recently the entire genome sequence of a homozygous diploid potato was made available for research by the Solynta company, indicating the willingness of private companies to share the benefits of this innovation more widely[25].

We recommend taking this one step further and suggest private sector companies establish collaborative partnerships in a breeding consortium that is fully dedicated to developing varieties that are uniquely suited to the needs of marginalized and impoverished farmers. Only then can the revolutionary potential of hybrid potato breeding be fully harnessed for food security. ❐

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Author contributions

The authors equally contributed to the conception of the work, the analysis, and drafting and revising the work.

Competing interests

The authors declare no competing interests.