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Participatory breeding in the Peruvian highlands: Opportunities and challenges for promoting conservation and sustainable use of underutilized crops

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Abstract

Underutilized crops tend to harbor high levels of genetic diversity, be maintained on-farm in small-scale farming systems and be relatively neglected by formal research and development strategies, including breeding programs. While high genetic variability allows these crops to adapt to marginal environments, inappropriate management practices and reductions in population sizes in individual farmers' plots may lead to productivity loss and poor harvests. This situation further limits their cultivation and use, notwithstanding the potential these crops may hold for diversification of agricultural systems, food security and market development. Peru hosts a wealth of native agrobiodiversity, which includes many underutilized crops. To improve their performance and promote their continued conservation and use, a participatory breeding program was developed on five underutilized crops of the Peruvian highlands; the breeding approach, based on a combination of evolutionary and participatory methods, is designed to achieve a balance between yield improvement and maintenance of genetic diversity. Preliminary results in quinoa and amaranth are encouraging, fostering further engagement of farmers by increasing availability of quality seed for downstream uses. However, methodological, financial and institutional issues need to be addressed for the effort to be expanded and upscaled. This paper provides an overall description of the initiative as well as a discussion on early results obtained in quinoa and amaranth, highlighting those aspects that make this approach particularly relevant for minor crops and identifying the opportunities and challenges for the initiative to move forward.

Key words: neglected and underutilized species, agricultural biodiversity, participatory breeding, conservation, food security

Introduction

Improving underutilized crops for sustainable agriculture

In the context of global economic and climatic change, there is increasing evidence that a new understanding of agricultural production intensification is required, which should embrace issues of sustainability, climate resilience, income generation, food security and sovereignty[1]. One of the major aspects of the discussions around sustainable agriculture focuses on crop diversity[2,3]. Concerns exist about the continued maintenance of a variety of crops in cultivation, the intra-specific diversity within them[4,5] and the implications for two global challenges: the need to ensure global food security and adapt to climate-induced environmental change. In this context, the need to reconcile agricultural intensification with maintenance of crop genetic diversity in the production system is emerging as a priority. It is thus argued that within the called-for new paradigm of agricultural intensification[6,7] an important, albeit not exclusive focus should be placed on a wider range of 'minor' crop species, for their relevance in small-scale farming systems and marginal agro-ecologies, where highly specialized commodity-based production models do not succeed.

One of the common features of underutilized crops is the relative lack of improved varieties and the prevalence of diverse landrace material grown in farmers' fields, a trend which is more or less pronounced depending on the species and context. Although landraces are best adapted to locally prevailing and frequently marginal and low-input growing conditions, they often suffer from poor yields from inbreeding depression due to population fragmentation in smallholdings and/or to the lack of appropriate seed management and conservation practices[8]. This in turn determines a general loss of appreciation of landrace material and its potential. On the other hand, improved varieties are often unavailable or expensive and thus inaccessible to subsistence producers and poorest groups; in addition, they don't always respond to the agro-ecological challenges of marginal areas nor farmers' preferences for their traditional uses. Therefore, improving the genetic basis of locally relevant underutilized crops and achieving relatively small increases in yields could greatly boost food production, income-generating opportunities and livelihoods[9] in vulnerable areas. It can pave the way for downstream developments, such as quality seed multiplication and dissemination among farmers and, where appropriate, value chain development based on local agricultural biodiversity.

Breeding approaches for underutilized crops

Worldwide, investments in capacities and funds for public breeding programs have been declining[10], while the private sector shows limited interest in crops without a well-organized value chain, consistent demand or market share. Also, conventional breeding approaches tend to determine a strong narrowing of the genetic variability in the final product, seeking for an ideal variety to be grown under the more controlled and homogeneous conditions of commercial agriculture[11]. On the contrary, maintenance of genetic diversity in crop populations is key to sustain production in the marginal and highly heterogeneous agricultural systems in which most underutilized crops are grown[12,13], while meeting traditional farmers' preferences, contributing to yield security and, where appropriate, supporting the development of value chains based on agricultural biodiversity. Given these considerations, two approaches to plant breeding—farmer participation and evolutionary methods—may be particularly relevant in the context of underutilized crop species.

The search for approaches suited to breeding for marginal areas and low-input farming systems started 50 years ago[14] and led to the development of the evolutionary plant breeding method[14,15]. In this approach, landraces of different evolutionary origins are assembled and recombined to enhance spontaneous or facilitated (through manual crosses) cross-pollination, with the resulting mixtures known as composite populations. Over several generations, the progenies are propagated in bulk and subjected to natural and human selection under various ecological conditions. In experiments with barley[14–16] and wheat[17,18] composite varieties have been found superior to leading high-yielding commercial varieties because they maintain a greater degree of genetic diversity which allows them to perform better under various environmental conditions.

Participatory plant breeding (PPB) is a long-standing concept and framework which has been applied in a number of developed and developing countries over the past 20 years[19]. It combines modern science with local knowledge, brings plant breeding back into farmers' hands and encourages a return to crop diversity[20]. PPB is generally undertaken with the aim of generating improved and adapted varieties for the smallholder, low-input agricultural systems; in this context and depending on the reproductive biology of the species, methods such as mass selection or evolutionary breeding are usually employed. These tend to generate more heterogeneous varieties compared to those used in commercial agriculture, where genetic uniformity is valued or even required to enable formal registration or plant variety protection. As a result, the resilience and adaptation of materials from these breeding approaches tend to be greater than those of varieties produced for optimal, controlled and high-input conditions of industrialized agriculture[20]. Furthermore, the involvement of farmers in the early stages of the breeding activity leads to greater adoption rates[21]. To our knowledge, no documented experiences of these approaches with underutilized crops exist in Peru.

The 'Conservation Breeding' Experience in the Peruvian highlands

Background and origins of the initiative

Peru is known as one of the world's ten 'mega-diverse' countries, for its rich diversity in ecosystems, species, genetic resources and associated cultures. Peru's biodiversity is one of the pillars of its national economy, directly sustaining a large part of the population, playing an important role in culture, science and technology, and providing essential environmental services in terms of soil fertility, air quality and water supply[22]. The country is an important centre of domestication and diversity for many crops[23,24]; some of these have acquired global relevance (e.g., the potato) while others, such as Andean grains, tubers and fruit species, have remained more locally distributed and relatively underutilized[25].

The UN Year of Biodiversity in 2010 significantly contributed to placing conservation and use of the country's biological heritage in the spotlight; among other initiatives, the Ministries of Environment and Agriculture, the National Agricultural Research Institute (INIA) and Bioversity International organized the forum 'Aprovechando la Agrobiodiversidad del Perú' ('Making the most of Peruvian Agrobiodiversity') to discuss opportunities and practical steps forward. The forum played a significant catalytic role in designing and/or consolidating initiatives, including the formalization of agrobiodiversity conservation areas, the establishment of inventories of local crops and landraces as a measure to prevent their 'misappropriation' and other actions aimed at fostering increased use of native agricultural biodiversity[26]. In the forum, a proposal was also put forward to test the application of an evolutionary and participatory breeding method which had been successfully applied in maize[27,28] on a number of minor crops in four marginal, mountain regions of the country (Ayacucho, Cusco, Junín and Puno). The method combines evolutionary and participatory approaches, and was named 'conservation breeding' to highlight the importance it places on striking a balance between improvements in landrace performance and maintenance of genetic diversity. Through the fundamental initial steps of germplasm collection and recombination, followed by farmer-led selection, the method strives to restore and maintain a set of relatively diverse (in terms of intra-specific diversity), productive and adaptable 'varieties' available to farmers. Five crops were prioritized for an initial pilot phase of the program, the choice being based on a combined assessment of the most relevant crops in the local farming systems, their potential for strengthening local food security and livelihoods and the existence of previous or on-going research in INIA's decentralized stations. The prioritized crops for this initial testing of the method include Andean grains and legumes whose characteristics are briefly explained in Box 1. Statistical data about their cultivation areas, compared with those of major Peruvian staple crops, are shown in Table 1. The breeding methodology described in the following section is applicable to all target crops, but has been completed only in quinoa and amaranth and early results will be described for these two species only.

Designing the methodology

Figure 1 summarizes the steps which are common to the breeding process of every target species. The initial collecting phase was designed so as to capture most of the genetic diversity available for a given crop, including those alleles which occur at low frequency and are related to important adaptive traits (e.g., drought or cold tolerance); these are particularly important for the continued and improved adaptation of these underutilized species to their growth environments. Some authors recommend choosing a sample size capable of capturing, with at least a 95% probability, all alleles occurring at a frequency greater than 0.05. This would imply the collection and bulking of seeds from 30 randomly chosen individuals in a fully outbreeding sexual species, or from 59 individuals in a self-fertilizing species[32]. Other authors raise the number to 100 plants for inbreeding species and 50 for outcrossers[33]. Guided by the effort to capture low-frequency adaptive alleles, and given the predominantly selfing nature of the target crops, seeds from at least 20 plants of each species were collected at different sites within each target region. It was generally impossible to collect seed from more than 20 plants at each collecting site, because of the small size of the surveyed fields; additional samples were obtained as grain from local markets and seed storage facilities of individual farmers after harvest, reaching a minimum total of 100 sampled plants in each target region. It is assumed that the grain from individual farmers' stocks or from the lots they sell on local markets represents a random mixture of all plants harvested that year.

Upon collecting and in collaboration with farmers, local variety names, preferences and uses were recorded. Samples were grouped into racial groups (i.e., landraces) based on the most notable morphological and agronomic characters (such as shape of the inflorescence, length of the growth cycle, color and shape of the grain), leading to a preliminary racial classification. The collection was sown in INIA's experimental stations located in the regions of collecting and, upon maturity, plants were again morphologically characterized to either confirm and complete the preliminary landrace identification or re-define groups. Equal numbers of seeds (around 100) from each identified group were used to produce the composite populations (one for each landrace group), which were sown in separate plots to be subjected to subsequent cycles of spontaneous recombination and selection. While the target species are described as predominantly inbreeding, higher than expected levels of cross-pollination have been

Box 1. Underutilized crops incorporated in conservative breeding

Pseudocereals: Andean grains

Amaranth (*Amaranthus caudatus*) is a hardy plant whose grains are high in proteins (12–16%) rich in essential amino acids such as lysine. It is high in calcium and phosphorus too. Unlike beans or true cereals, amaranth has neither hulls nor the high saponine content which increases processing times in quinoa. The grain can be consumed either as it is, popped or transformed into flour. The residues are traditionally used as fodder and the inflorescences for ornamental purposes[25].

Cañihua (*Chenopodium pallidicaule*) is the least known of the Andean grains. It is not fully domesticated and it is characterized by high protein content (15–19%), particularly rich in sulfur-containing amino acids. Seed shattering is a major production problem, together with the low average yields that, however, can be significantly improved (up to 700 kg ha^{-1}) with appropriate management strategies[29]. According to local knowledge, cañihua possesses medicinal properties against dysentery and altitude sickness, because of its high iron content[25].

Quinoa (*Chenopodium quinoa*) is the best known Andean grain; as the others, it is rich in high-quality proteins. The grain has a coating of bitter-tasting saponins, making processing long and time-consuming. This bitterness has beneficial effects during cultivation, protecting the crop from pests and birds. Throughout the history of indigenous Andean people, it has been known as the 'mother grain' because of its importance and nutritional value[30]. Since the 1990s, quinoa has found an important niche in US and European markets and the growing demand and high prices on international markets have determined a strong expansion of the production, especially in Peru and Bolivia.

Legumes

Popping beans (*Phaseolus vulgaris*) are important in the diet of the Andean rural population, as well as being used in baking and confectionery. Importantly for poor households, popping beans require little energy for cooking, since the seed is roasted, not boiled. Morphologically these beans, locally known as ñuñas, are undistinguishable from other varieties but their grains have the unique capacity to burst upon toasting. The resulting popped product is soft and palatable. The combination of factors determining the popping capacity is unknown; however, the shape of the seed, the elasticity of its peel and the quantity and quality of the starch play a role[31].

Andean lupin (*Lupinus mutabilis*) is a multipurpose crop with a high nutritional value, similar to that of soybean, containing up to 40% protein and 16% fat in the fresh grain. Lupins contain alkaloids which confer tolerance to many parasites and pests but also make processing for human consumption longer and more laborious, partially explaining its underutilization. Besides its use as food, it contributes to soil fertility and is adapted to a wide range of climatic conditions; its residues, thanks to their high cellulose content, are used as a fuel[25].

reported in the literature or observed by local experts and have been attributed to increased pollinators' frequency or variability of environmental conditions[34–38]. This led to the decision to test on these species an approach based on spontaneous recombination, which was developed for outcrossing maize[28], expecting less spectacular but still potentially significant yield gains, especially over the long term. At flowering, any damaged or diseased inflorescence was eliminated, in order to foster recombination only among healthy individuals; at harvest time seed was selected from the most representative plants of the composite, i.e., those which best expressed the key morphological traits of their racial group. The seeds from the selected plants were made available to interested farmers during a specially organized open house event at the experimental stations. Farmers sowed the seeds in their own fields at the next cropping season and the first cycle of farmer-led recombination and selection was started on the progeny. The plants were sown in farmers' plots, flanked by a pollinating population consisting of a mixture of seeds (in equal number) from the best-performing plants identified within the composite in the previous cycle. At each harvest, 20% of best-performing plants were selected and their progeny were subjected to the next cycle; the new pollinating population was made up of the mixture of seeds from the best-performing individuals (i.e., the gradually improved composite) identified in the latest cycle, and so on. The yearly genetic gain was measured by comparison with the original composite obtained in the first cycle.

While inputs from INIA scientists mostly contributed to the initial grouping of the collected material in composite populations and to the dissemination of improved seed selection and reproduction practices, farmers are the key actors in identifying the best-performing plants for traits of their interest during the selection process and in reproducing and making available the seed to other cultivators for subsequent cycles. Farmers are being assisted and trained in best practices for seed selection and storage, in order to make high-quality seed of the gradually improved composites available in the community. Nutritional characterization of the materials included in the breeding effort was carried out by INIA specialists, in order to evaluate the potential contribution

Table 1. Cultivation areas of the five target crops and comparison with three major Peruvian staples.

Crop	Common name	Scientific name	Area (ha)[1]	Area compared to maize (%)	Area compared to potato (%)	Area compared to rice (%)
Amaranth	Kiwicha, Achita, Amaranto	*Amaranthus caudatus*	1173	0.25	0.38	0.49
Canihua	Cañihua	*Chenopodium pallidicaule*	5424	1.15	1.76	2.27
Quinoa	Quinoa	*Chenopodium quinoa*	29,639	6.29	9.60	12.40
Popping bean	Frijol ñuña	*Phaseolus vulgaris*	1164	0.25	0.38	0.49
Andean lupin	Tarwi, Chocho	*Lupinus mutabilis*	7310	1.55	2.37	3.06
Maize	Maíz	*Zea mays*	471,023			
Rice	Arroz	*Oryza sativa*	308,668			
Potato	Papa	*Solanum tuberosum*	239,094			

[1] Average cultivation area over 2008–2011 (source: Peruvian Ministry of Agriculture, at http://frenteweb.minag.gob.pe/sisca/?mod=consulta_cult).

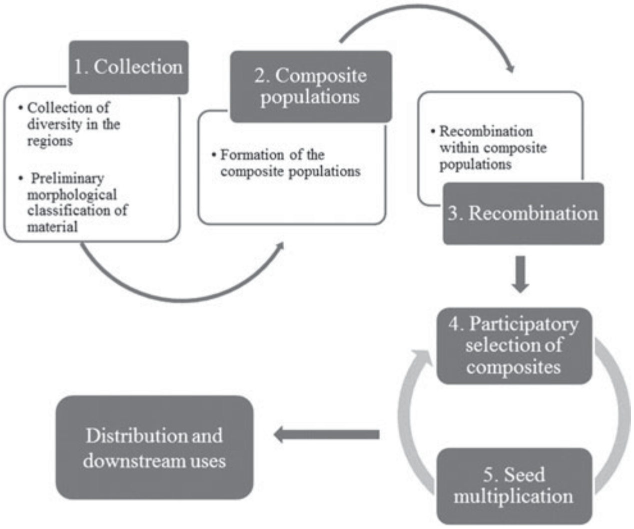

Figure 1. The steps of the breeding cycle.

of these crops to local diets and thus reinforce the message on the importance of their continued conservation through improved management and use.

Early Results, Implications for Conservation and use of Underutilized Species, and Ways Forward

During the initial collecting phase, a total of 940 samples were collected, distributed between target species as described in Table 2. Quinoa (*Chenopodium quinoa*), amaranth (*Amarantus caudatus*) and cañihua (*Chenopodium pallidicaule*) were classified based on traits such as panicle shape, color and architecture, grain color, stem and leaf color. The two legume species (*Phaseolus vulgaris* and *Lupinus mutabilis*) were characterized based on grain color and length of the growth cycle. In addition to generating the basic material for the breeding process, the collection, characterization and evaluation of crop genetic resources are key steps for setting a baseline of their on-farm conservation status in an eco-geographical region, based on which periodic assessments and monitoring of genetic erosion can be carried out[39].

Table 2. Samples collected for each target species and used for establishing the composite populations (results were unavailable for cañihua, a species for which the process is still in its early stages).

Crop	Number of samples collected	Number of composites established
Amaranth (*Amaranthus caudatus*)	266	12
Cañihua (*Chenopodium pallidicaule*)	80	NA
Quinoa (*Chenopodium quinoa*)	280	13
Popping bean (*Phaseolus vulgaris*)	235	5
Andean lupin (*Lupinus mutabilis*)	79	4

Based on morphological characterization, the samples were grouped into composite populations: 66 composites were formed in quinoa, five in cañihua, 27 in amaranth, 19 in Andean lupin and 16 in popping bean. The generation and management of composite populations, given their potential to serve as 'reservoirs of genetic adaptability'[40,41], is considered an effective mean of on-farm maintenance of plant genetic resources, while striving for gradual improvements in performance. A composite population encloses much more diversity than any single farmer's population and thus enables selection to be more effective. Across quinoa and amaranth composites, consistent yield improvements were observed over two or three (depending on the composite and locality) recombination cycles. Quinoa landraces 'Negras' and 'Chullpi' in the Puno region experienced a gain of 17.35% and 7.25%, respectively, after three cycles, when compared to the average yields of the original composite. The yield gain after two years of 24 quinoa composites and of 14 amaranth composites tested in Ayacucho was

Table 3. Nutritional content of selected composites in quinoa and amaranth, and averages for each species.

Region of collection	Crop	Composite name	Water (g/100 g)	Protein (g/100 g)	Carbohydrates (g/100 g)	Energy (kcal/100 g)	Dietary fiber (g/100 g)	Ash (g/100 g)	Fat matter (g/100 g)	Vitamin C	Calcium (mg/100 g)	Iron (mg/100 g)
Sta Ana	Quinoa	B	10.6	11.1	70.0	374.8	2.3	2.7	5.6	0.5	33.5	3.6
Sta Ana	Quinoa	A	9.5	14.5	67.2	379.0	2.9	3.0	5.8	0.5	33.6	3.5
Canaan	Quinoa	CQA-037 AMARILLO	9.9	16.4	65.1	373.7	3.0	3.3	5.3	0.0	70.0	6.0
Canaan	Quinoa	CQA-048-2 BLANCO	9.3	11.3	69.0	384.2	3.7	3.4	7.0	0.5	70.5	5.7
Illpa	Quinoa	CHULLPI	6.9	12.3	71.4	393.3	3.5	2.9	6.5	0.5	107.0	10.5
Illpa	Quinoa	BLANCO GRANO GRANDE	8.0	15.9	68.6	384.8	3.5	2.3	5.2	0.5	100.0	9.4
Illpa	Quinoa	NEGRA	8.3	16.0	68.2	379.1	5.9	2.8	4.7	0.5	110.0	8.6
	Quinoa averages		8.9	13.9	68.5	381.3	3.5	2.9	5.7	0.4	74.9	6.7
Canaan	Amaranth	CKA-089-3	7.6	12.2	71.4	388.4	4.2	2.8	6.0	0.3	170.0	6.4
Canaan	Amaranth	CKA-009-3 PANOJA GUINDA	9.1	11.2	68.5	391.7	4.0	3.1	8.1	0.3	133.0	11.7
Canaan	Amaranth	CKA.029-2 BLANCA DECUMBENTE	9.0	11.0	66.9	405.2	3.8	2.7	10.4	0.3	120.0	6.1
Andenes	Amaranth	ANDAHUAYLAS C	9.0	14.6	69.3	373.4	4.5	2.9	4.2	0.3	109.5	7.0
Andenes	Amaranth	ANDAHUAYLAS A	7.5	15.1	68.7	390.1	3.5	2.6	6.1	0.3	138.6	8.3
Andenes	Amaranth	ANDAHUAYLAS B	8.8	14.6	68.3	381.1	4.0	2.8	5.5	0.3	90.1	6.9
	Amaranth averages		8.5	13.1	68.8	388.3	4.0	2.8	6.7	0.3	126.9	7.7

8.75% and 8.17%, respectively. Several studies have shown positive yield results either after controlled crossing for self-pollinating species or open pollination among populations of outcrossing species. Recombination within composite populations of maize brings dramatic reductions in inbreeding depression and yield increases[42]; positive yield results have been observed in predominantly inbreeding crops such as lentils, wheat and pearl millet[43–45] through controlled crosses. In the preliminary results described here, the observed yield gain in primarily self-pollinating species may be due to higher than expected levels of outcrossing and thus genetic recombination or to agronomic benefits of using crop mixtures. We have already discussed the possibly higher than expected rates of recombination in the species under consideration here, something that has been observed in other cereal species and particularly under variable environmental conditions[46–48]. Cultivar mixtures are a type of within-field diversification which has been used particularly in the context of disease management and yield improvement[49–50].Wheat, barley and rice are planted in intraspecific mixtures to prevent disease outbreaks and spread in the USA[51], Germany[52] and China[53]. In reviews of studies about crop mixtures of mostly grains and legumes, yields were often slightly greater than the mean of the component cultivars[54–55], while results are more mixed in important horticultural species as the tomato[56]. It has also been observed that yield stability of mixtures in cereals can exceed that of individual components across a range of soil types[57]. Further selection cycles and longer-term statistical analyses are needed to confirm the stability over time of these results, to determine the drivers of the increases in yield and to extend the experience to the other priority crops. Evolutionary breeding is based upon long time frames (up to 30 generations) for validating the adaptation and yield advantages of the composite populations[58] and thus evaluate the capacity of the genetic diversity they enclose to consistently improve food security and livelihoods. In the future, the use of controlled crosses among well-characterized parents carrying known desired traits could be introduced to further enhance recombination in partially or predominantly inbreeding species; molecular characterization of the composites, for example through microsatellite markers, could shed light on the heterozygosity level of the populations and thus on the percentage of cross-pollination, which in turn can allow a decision on the opportunity of introducing controlled crosses in the breeding strategy.

Early evaluations of the composites' nutritional content (Table 3) confirm the high nutritional value already observed in Andean grains[59–60], particularly in terms of content of protein, fat and essential minerals. Protein content of the quinoa materials under study (13.93 g/100 g dry matter) was similar to previously reported values, whereas that of the amaranth composites (13.12 g/100 g dry matter) was lower than that previously observed[59] but still considerably higher than the content of other major staple crops[61]. Fat content was higher than that described in other studies[59–60], being on average 5.73 g/100 g in quinoa and 6.72 g/100 g in amaranth. In terms of minerals, quinoa samples contained an average of 74.94 mg/100 g calcium and 6.67 mg/100 g iron, while amaranth contained an average of 126.87 mg/100 g calcium and 7.73 mg/100 g iron. The content of these two minerals is admittedly lower than that reported for other quinoa and amaranth materials, possibly due to natural variability among different sample sets, but still significantly higher than the averages described for other major cereals, such as wheat and rice[61].

The farmer-based multiplication of the materials at each selection cycle is an important contribution to strengthening informal or local seed systems and fostering diffusion of gradually improved materials, in turn upscaling the impact of the breeding process on food security and biodiversity conservation[9]. However, one of the major technical and institutional bottlenecks downstream of most processes of participatory plant breeding resides in the phases of quality assurance and dissemination of improved seed beyond the immediate participants to the breeding program. As in most countries, formal procedures for varietal release, registration and seed multiplication in Peru are regulated by the seed law[62] and overseen by a government-appointed committee (Comité Gubernamental de Semillas). Registration is based on scientific reports about performance, distinctiveness, uniformity, stability and quality of the new variety. Such a system overlooks the reality of small-scale farmers who still provide most of the seeds for agricultural production through the informal system, i.e., without any certification or registration. If even for an important staple such as potato, national data in Peru show that the formal system is able to provide seed for only 2% of the national production[63], its limitations are even greater for varieties of underutilized crops. Encouragingly, in Peru a space exists for designing such mechanisms under the current seed law, which contemplates a 'common seed' category, exempt from the official certification scheme but still required to comply with minimum quality standards. If the breeding effort is improved and expanded further, schemes for certification and distribution of local genetic materials will have to be explored, requiring a better understanding of seed registration issues, local property rights, ownership and benefits associated with the application of local knowledge, in order to recognize and provide incentives for the continued involvement of farmers as essential actors in this process.

Conclusions

Given Peru's rich agricultural biodiversity and the persistence of pockets of poverty and malnutrition, especially in rural areas[64], investing in sustainable improvements of local crop productivity and competitiveness in close collaboration with smallholders may be an effective long-term strategy to sustain national food security, sovereignty and health. In this direction, the described combination of participatory and evolutionary breeding approaches is a particularly interesting way forward to rescuing and promoting the value of native, relatively underutilized crops.

However, many challenges lie ahead in order to move the process forward, starting with validating and improving the methodology across the different target crops. Not only does the characterization and selection process need to be continued over a number of years, but also new tools, such as molecular characterization of the samples and the possible introduction of controlled crosses, should be explored. Distribution of the diverse, improved materials through some innovative form of variety registration can open opportunities to develop agrobiodiversity-based value chains[65] grounded on specific traits of interest carried by each landrace. Although concerns have been raised on the appropriateness of market mechanisms alone as means to promote underutilized species, it cannot be denied that value chain development and access to markets of agricultural products provide opportunities for farmers to increase their income, and play an important role in poverty reduction[66].

Finally, a wealth of underutilized species exist in Peru, most of which with significant potential. While the choice of five pilot species fell on relatively better-known crops, for which technical expertise and organized farmer groups already existed, expanding and upscaling the application of conservation breeding will require an agreed process for designing participatory prioritization strategies in each region, as well as consistent, long-term funding. Furthermore, breeding for improved varieties is only one element of efforts to enhance crop production; it should be accompanied by initiatives to improve agronomic practices and technologies for the cultivation of these crops, liaising with the ongoing crop-based program in place within the national agricultural research system.

The initiative described here and its preliminary results are only a step, albeit a crucial one, towards improved conservation and sustainable use of underutilized genetic resources in the framework of agricultural development, food security and health. Institutional support and multidisciplinary linkages across sectors and at local to national levels will be essential to embed this initiative in long-term strategies, making it sustainable over time.

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