23 Breeding *Phaseolus* for Intercrop Combinations in Andean Highlands

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Rationale or Impetus for Undertaking the Breeding Strategy

The common bean, *Phaseolus vulgaris* L., is by far the most important pulse crop in Latin America, its centre of origin and diversity. The species is the most valuable source of dietary protein, particularly among the low-income populations. Small farmers are the principal producers of beans, often as a secondary crop in association with cereals, root and tuber plants, and vegetables (Francis, 1986; Woolley *et al.*, 1991). A high proportion of the seeds is directly consumed on the farm or traded only in local markets. Despite their nutritional importance, production growth rates have been declining in Latin America, with dry seed yields averaging less than 600 kg ha^{-1} (Woolley *et al.*, 1991; Lobo, 1994). This is particularly true for the low-input intercropping systems of the Andean highlands, where beans are suffering from several constraints: high incidence of diseases and insect pests, soil mineral deficiencies, cold or drought stresses, poor crop management, competition with associated crops and lack of improved seeds. Most of the landraces and improved varieties of the common bean are susceptible to one or more of these production constraints, preventing the realization of their full yield potential and causing production instability from one year to the next.

One way to increase seed production of common bean in the Andean highlands is to develop a breeding process well adapted to the traditional multiple-cropping systems. In the small-scale subsistence farms of the regions, *P. vulgaris* and other *Phaseolus* cultigens are very often associated with maize, in small dispersed plots, mainly on sloping land of limited fertility and prone to soil erosion. In such marginal conditions, the association ensures reduced variability in total biomass and yield, arising mainly from compensatory effects among the crops, lower weed and erosion problems due to better soil cover, and reduced incidence of pests and diseases. Intercropping also gives a greater diversity of diet and a more stable source of income, particularly for farmers with limited land resources (Francis, 1986; Baudoin and Marechal, 1987; Baudoin and Camarena, 1994). However, when considering the benefits of the association, we

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should not underestimate one major obstacle: the substantial interspecific competition of the associated components in environments sometimes limited in natural resources (water, nutrients and light). This competition affects particularly understorey crops, such as the *Phaseolus* beans.

In this study, we consider breeding *Phaseolus* beans for intercrop combinations in Andean regions, ranging from 2000 to 3600 m altitude. The data and discussions come mainly from collaborative projects at Gembloux Agricultural University (Belgium) developed with the Centro Internacional de Agricultura Tropical (CIAT), Colombia, the Corporación Colombiana de Investigación Agropecuaria (CORPOICA), Colombia, and the Universidad Nacional Agraria La Molina (UNALM), Peru. In the target regions of Colombia and Peru, two main cropping patterns prevail. In the first pattern, found in areas with a single rainy season (Ancash, Cajamarca and Cusco in Peru; Cauca, Nariño and Putumayo in Colombia), maize and beans are mainly planted simultaneously under mixed, row or hill intercropping, with beans climbing on the maize stems. In the second pattern, found in eastern Antioquia of Colombia under bimodal rainfall distribution, maize is planted in the first rainy season while beans are broadcast into the maize during the second season at a period corresponding to the physiological maturity of the cereal. This system is called relay cropping, with 1–2 months' overlap of maize and bean cycles. The stems of the strong-stalked highland maize offer a good support for the long and twisted branches of climbing beans.

In the two patterns, bean genotypes are always of indeterminate growth habit, with a strong climbing ability and a long growth duration, requiring usually 7–10 months to reach the fruit ripening stage. This slow-maturing trait is very frequent in highland areas affected by low temperatures during the cultural season. The length of the bean growth cycle is similar to that found in local traditional maize varieties. In the cultural associations of the target regions, the cultivated *P. vulgaris* genotypes belong to a rather limited number of large-seeded classes, i.e. in Colombia: mainly Cargamento (with cream-beige speckled seed colour) and Mortiño (with purple seed colour); in Peru: mainly Panamito and Caballero (with white seed colour), Canario and Bayo (with yellow seed colour) and Nuñas (popping beans with striking colours and patterns).

Whatever the type of cultivated genotypes and cropping systems, beans are very often considered as a high-risk crop, prone to many diseases and not receiving a good crop husbandry management by small farmers (such as use of improved seeds, regular weeding, organic matter application, chemical treatment against pest, etc.). We decided therefore to rank our objectives according to this situation. First priority was given to multiple disease resistance, a prerequisite for better response of beans to improved crop husbandry and food marketing. Secondly, priority was given to fitting plant architecture and yield components into the frame of traditional intercrop combinations.

To achieve these objectives, one key factor of our breeding strategy consisted of exploiting fully the interspecific diversity available in *Phaseolus*. Indeed, within the common bean primary genepool, insufficient genetic variation has been found to overcome several major production constraints (Baudoin *et al.*, 1995). Past experiments conducted mainly in Colombia demonstrated the excellent potential of two *Phaseolus* species, of Mesoamerican and north Andean origin: *P. coccineus* L. and *P. polyanthus* Greenm. Both species are well adapted to Andean highlands (above 2000 m) and belong to the secondary genepool of *P. vulgaris* (Baudoin *et al.*, 1992). The species show several desirable agronomic attributes, such as pest, insect and disease resistance, cold tolerance, lodging resistance due to thick stem bases, presence of tuberous or fibrous root systems allowing a perennial cycle, long epicotyls and racemes, and a large number of pods per inflorescence (Schmit and Baudoin, 1987). The base germplasm collection is maintained at CIAT and represents genetically broad unimproved germplasm, found as a garden or backyard crop in small farms or as a weedy vine climbing on trees at the border of montane rain forest (Schmit and Debouck, 1991). In the genetic improvement of beans for multiple cropping systems, these two food legumes have a value in their own right and could be bred as distinct crop, particularly for higher and colder Andean regions. They can also be utilized in interspecific crosses with *P. vulgaris*, to introgress genes controlling useful traits not commonly present in the primary common bean genepool.

Methods and Strategy Used

Breeding approach

The best way of achieving significant progress in breeding for multiple cropping systems is to adopt a farming systems approach, involving diagnosis, on-farm experimentations and active farmer participation at an early stage (Steiner, 1990; Woolley and Davis, 1991; Sperling *et al.*, 1993). Evaluation and breeding are carried out under cultural conditions representative of the traditional cropping systems but in conditions sufficiently uniform to allow reasonably reliable selection. In this case, the experimental design should mimic the two prevailing cultural associations (relay cropping and simultaneous intercropping) at some stages of the breeding process.

Although any genetic modification of one crop will have an effect on the other associated crop, it is more efficient to breed each species separately, the other partner being represented by a locally well-adapted cultivar. Indeed, Davis and Garcia (1983) demonstrated that when indeterminate climbing beans are intercropped with different maize cultivars, the interaction between the two associated crops is usually not significant. It is therefore not worthwhile selecting both cereal and food legume simultaneously. In these investigations, priority was given to the understorey crop, the *Phaseolus* beans. Segregating hybrids or unimproved populations of both *P. coccineus* and *P. polyanthus* were selected in association with one or two representative maize cultivars for each of the two cropping systems prevailing in the target regions. These maize cultivars are well adapted in the Andean highlands, have strong stalks to provide support to long and twisted branches of beans with indeterminate growth and are relatively resistant to lodging.

Although the desirability of selecting under the target intercrop combinations is obvious, the cost and complexity of such investigations often compel the breeder to carry out part of the field trials under single cropping. This is usually advised for early hybrid generations and qualitative traits. Quantitative traits or traits of specific adaptation are evaluated in more advanced generations, in relevant multiple cropping situations (Francis, 1985, 1986).

As the objectives of the breeding programme are not to introduce selectively a few genes in some elite cultivars but rather to broaden the genetic base of locally adapted varieties, a population improvement scheme was adopted. The aims were to break up unfavourable linkage blocks and to incorporate a wider diversity of genetic resources into forms that can be further exploited by small farmers or integrated in more conventional varietal improvement (Poehlman, 1987).

Description of the breeding method

The breeding methodology relied mainly upon the genetic wealth available in the two species: *P. coccineus* and *P. polyanthus*. At the onset of the research project (1986), the CIAT base collection contained 1570 populations, divided as follows: 1013 and 496 cultivated forms of, respectively, *P. coccineus* and *P. polyanthus*, and 61 wild forms closely related to *P. coccineus*. Most populations (73%) came from Mexico and Guatemala; the other important countries of origin were Puerto Rico, Costa Rica, Colombia, Venezuela and Bolivia (Schmit and Baudoin, 1987). The genetic improvement of *Phaseolus* beans using this germplasm collection followed a gradual process involving several activities.

Seed increase of the collection

The two species are characterized by an outcrossing breeding system ascribed chiefly to the extrorse stigma and its position relative to the anthers. An appropriate seed-increase method was therefore used which maintained genetic integrity and total variability of the separate populations. Multiplication was carried out in two research stations of Colombia: Popayan (altitude 1750 m, Cauca) and Rionegro (altitude 2200 m, Antioquia). For each population grown in mesh cages, daily manual pollinations on several plants were made with a pollen mixture from all the flowering individuals (Vanderborght, 1983). This was a tedious and costly method but was worthwhile to prevent a dilution of useful genes, which would have occurred in a more open system of mass reservoir maintenance. Seed samples from about 800 populations were produced from this seed increase operation and were available for evaluation trials.

Evaluation of the collection

Trials were first conducted in the two Colombian stations of Popayan and Rionegro. Priority was given to plant architecture and yield component characters (such as stout main stems, moderate branching, long racemes, high pod setting rates and large seed size), earliness in maturity, adaptation to poor soil, cold tolerance and, more especially, resistance to the major diseases prevailing in Andean highlands: *Ascochyta* leaf blight (due to *Phoma exigua* var. *diversispora* (Bubak) Boerema), anthracnosis (due to *Colletotrichum lindemuthianum* (Sacc. and Magn.) Scribner) and angular leaf spot (due to *Phaeisariopsis griseola* Sacc.). Among the three, *Ascochyta* leaf blight appeared the most destructive enemy of beans in the target regions. On local *P. vulgaris* varieties, early attack of *Phoma exigua* var. *diversispora* can completely destroy leaves and pods and cause 74% yield losses in the Andean highlands. For this reason disease nurseries were established in Rionegro and Popayan for the years 1987 and 1988. The nurseries included 285 populations selected on the basis of their geographical distribution, using a randomized complete block design with three replications, and three locally adapted large-seeded varieties of *P. vulgaris* as control. The bean genotypes were single cropped or intercropped with maize (Schmit and Baudoin, 1992). Disease evaluation of *Ascochyta* leaf blight relied either on natural or artificial inoculation, and scores, based on a 1–9 severity scale (van Schoonhoven and Pastor-Corrales, 1987), were taken at three different stages: flowering, pod filling and seed physiological maturity.

Creation of interspecific hybrids

The objectives were to increase the genetic diversity of the locally adapted Andean cultivars of *P. vulgaris*, adding useful genes from *P. coccineus* or *P. polyanthus* populations identified mainly for their high disease resistance (particularly to *Phoma*). Crosses were made in the greenhouses of the University of Gembloux, using two systems: direct hybrids between *P. vulgaris* and one of the two donor species (with the help of embryo culture for some specific combinations) or indirect hybrids involving three or four parents with a wild *P. coccineus* form as a first maternal parent. Several genotypes of the latter were identified for their high combining ability with *P. vulgaris* in previous experiments (Baudoin *et al.*, 1992). The presence of wild *P. coccineus* cytoplasm favours interspecific gene exchange between the recurrent *P. vulgaris* parent and the donor parent (either *P. coccineus* or *P. polyanthus*). Such complex crosses, with *P. coccineus* cytoplasm, avoid a quick reversal towards the recurrent *P. vulgaris* parent and consequently the loss of useful genes from the donor parent (Baudoin and Maréchal, 1991).

Field breeding in Colombia and Peru

Breeding work was carried out in several research stations representative of the target Andean regions – in Colombia: Popayan, Rionegro and Pasto (altitude 2710 m, Nariño); in Peru: Chiquian (altitude 3550 m, Ancash) and other sites of Ancash, Cajamarca, Cusco and Lima Departments, at altitudes ranging from 2200 to 2800 m. Trials were carried out separately for the two types of material: *P. coccineus* and *P. polyanthus* bred as a distinct crop and the interspecific combinations created at Gembloux. For the two species, the selection units consisted of tested populations and single plants within the best populations. Open-pollinated seeds from progeny of selected plants or populations formed the next generation. In advanced generations, the most interesting populations were field isolated and selected at within-population level. For the interspecific crosses, hybrid breakdown, zygotic elimination and reduction in heterogenetic recombination impeded the following up of any kind of single plant, mass or bulk selection. The most appropriate breeding methodology adopted was cumulative or recurrent selection, designed to maintain a good state of heterozygosity during several generations and to increase the probability of crossing over in between linked genes (Baudoin and Maréchal, 1991). The breeding scheme included reselection at each generation with intermating of selected plants to provide genetic combination and breakage of unfavourable linkage. Another similar methodology adopted for such interspecific hybrids was congruity backcrossing. This method consisted of recurrent backcrossing to each parent (both the recurrent *P. vulgaris* and the donor species) alternately at each generation. This procedure gave an increased fertility level of hybrid genotypes and maintained a balanced set of genes from the two species over several generations (Baudoin *et al.*, 1995). In these two breeding schemes, intermating was carried on during several seasons, with a constant flow of new interspecific hybrids added to the recombination nursery. The purpose was to develop mixed-genotype populations, with a high frequency of favourable genes and enough variability for adaptation to a wide range of microenvironments (representing the small-scale Andean farms).

Field breeding of *P. coccineus, P. polyanthus* and interspecific combinations was conducted during the first generations at on-station level, in single cropping. The emphasis was on traits of interest whatever the cropping system involved, e.g. disease resistance, seed coat colour, seed size or earliness in flowering. For advanced generations, breeding trials were conducted at both on-station and on-farm levels, in relay or intercropping systems. Selection, at this stage, concerned traits with specific interest for multiple cropping systems and were mostly of a quantitative nature: for example, competitive ability with the associated maize crop, tolerance to shade, rapid seedling growth, vegetative vigour, harvest index and dry seed yield (Baudoin *et al.*, 1997).

Figure 23.1 illustrates the outline of the breeding scheme

Results to Date

Evaluation of *P. coccineus* and *P. polyanthus* germplasm collections

The disease nursery trials in the two highland stations of Rionegro and Popayan demonstrated the high resistance levels of the two donor species to *Ascochyta* leaf blight, compared with the susceptibility of the control *P. vulgaris* variety (Table 23.1).

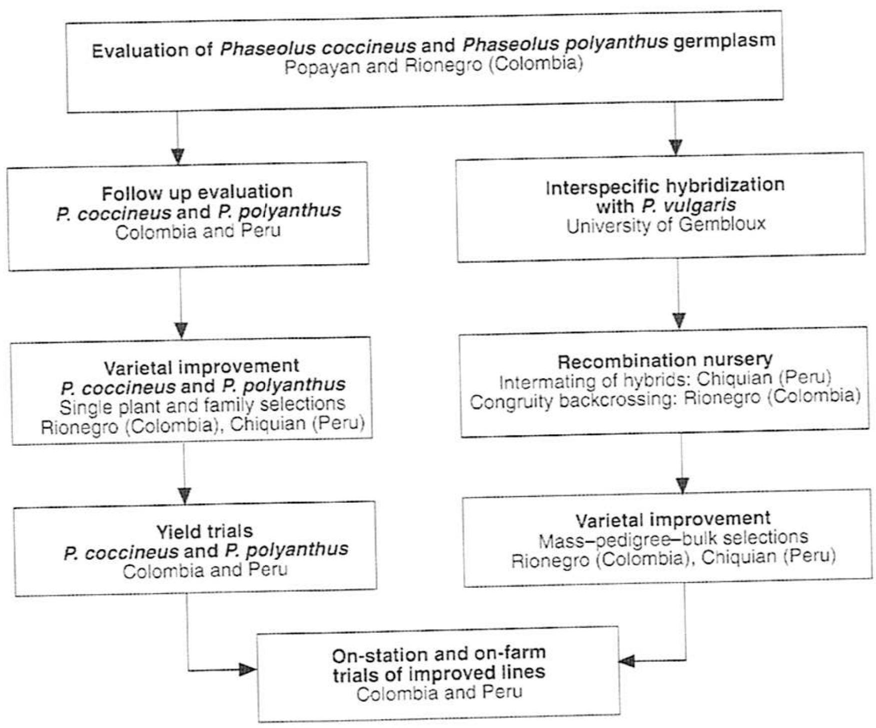

Fig. 23.1. Outline of the breeding scheme.

Table 23.1. Field reaction of *P. coccineus* and *P. polyanthus* populations to *Ascochyta* leaf blight at Popayan and Rionegro (Colombia).

	No. of populations in the three reaction classes[a]		
Species and site	Resistant (score 1–3)	Intermediate (score 4–6)	Susceptible (score 7–9)
Phaseolus coccineus			
Rionegro	76	19	—
Popayan	7	12	1
Phaseolus polyanthus			
Rionegro	110	—	—
Popayan	60	—	—

[a]Scores recorded at the stage of seed physiological maturity.

The 170 *P. polyanthus* populations showed outstanding resistance, with most accessions (64%) exhibiting no symptoms in the two stations. The best ones originated from Colombia, Venezuela and Mexico. The reaction of *P. coccineus* was more variable, with 83 populations classified as resistant, 31 classified as intermediate and one classified as very susceptible. The best genotypes originated from Costa Rica, Mexico and Guatemala. We also noticed the highest level of resistance from populations collected from sites above 2000 m, where climatic conditions (high humidity and cool to moderate temperatures) favour infection by the fungus. In the same nurseries, all the *P. coccineus* and *P. polyanthus* populations also showed an excellent reaction to the other two prevailing fungus diseases: anthracnosis and angular leaf spot, while a severe attack of these diseases occurred on *P. vulgaris* controls. According to genotypes and locations, dry seed yield of *P. coccineus* and *P. polyanthus* ranged from 250 to 3500 kg ha^{-1}, with a growing period of 6–7 months. Dry seed yields of *P. vulgaris* ranged from 150 to 1200 kg ha^{-1}, but with a shorter growing period of 4–5 months.

Additional trials were conducted from 1989 in the same Colombian stations and in Pasto (Nariño) and Peru (mainly Chiquian), covering a wider geographical distribution of the germplasm collection (with a total of 400 populations). These observations confirmed the field resistance to *Ascochyta* leaf blight in the two species and revealed high variability in growth duration, plant architecture and yield components.

Creation of interspecific hybrids

Table 23.2 shows the interspecific hybrid types, developed in Gembloux from 1985 to 1989. A total of 360 genotypic combinations of direct crosses and 220 genotypic combinations of complex crosses were obtained. The highest rates of success were obtained in crosses using *P. vulgaris* as female parent and a single donor species. Hybrids with *P. polyanthus* cytoplasm required *in vitro* embryo culture, due to starvation of embryos at a very early developmental stage (Mergeai *et al.*, 1997). In the complex crosses, we identified three wild forms of *P. coccineus*, from Mexico, which showed a good crossing compatibility with *P. vulgaris*. Hybrids with such wild cytoplasms could act as a bridge

Table 23.2. Creation of interspecific hybrids with *Phaseolus* beans.

Direct crosses

Female		Male	No. of genotypic combinations
P. vulg.[a] cv[d]	×	*P. cocc.*[b] cv	120
P. vulg. cv	×	*P. poly.*[c] cv	220
P. poly. cv	×	*P. vulg.* cv	2
P. cocc. wld[e]	×	*P. vulg.* cv	13
P. cocc. wld	×	*P. poly.* cv	2
P. poly. cv	×	*P. cocc.* cv	3

Complex crosses

Female				Male	No. of genotypic combinations
(*P. cocc.* wld	×	*P. vulg.* cv)	×	*P. vulg.* cv	14
(*P. cocc.* wld	×	*P. vulg.* cv)	×	*P. cocc.* cv	88
(*P. cocc.* wld	×	*P. vulg.* cv)	×	*P. poly.* cv	18
(*P. cocc.* wld	×	*P. poly.* cv)	×	*P. vulg.* cv	92
(*P. poly.* cv	×	*P. cocc.* cv)	×	*P. vulg.* cv	4
(*P. poly.* cv	×	*P. vulg.* cv)	×	*P. vulg.* cv	4

[a]*P. vulg.* = *P. vulgaris*; [b]*P. cocc.* = *P. coccineus*; [c]*P. poly.* = *P. polyanthus*;
[d]cv = cultivated forms; [e]wld = wild forms.

to combine genes from both the recurrent (*P. vulgaris*) and donor *P. coccineus* or *P. polyanthus*.

Field breeding

At the onset of the breeding programme, selection focused on dry seed yield (above 1500–2000 kg ha^{-1} according to the sites), earliness in flowering (from 90 to 130 days), seed size (with a preference for large-seeded genotypes with 100-seed weight above 45 g) and disease resistance (mainly to *Ascochyta* leaf blight). By doing so, we retained in each station 80–100 populations from each of the two species, *P. coccineus* and *P. polyanthus*, and around 200 interspecific lines from the crosses developed in Gembloux.

Single plant and family selections were carried out with *P. coccineus* and *P. polyanthus* materials, using different cropping patterns: single cropped, relay and intercropped with maize. The best lines, from 15 to 30 in each of the two species, were tested in multilocational yield trials with locally adapted cultivars of *P. vulgaris*. Table 23.3 shows the performance of promising lines in single and multiple cropping systems in two Colombian stations. No fertilizer treatment and no protection against diseases were practised. In Rionegro, the two improved lines of *P. coccineus* and *P. polyanthus* outyielded the local common bean variety. This reflects partly their very good disease

Table 23.3. Seed production of improved *Phaseolus* lines in single cropping and association (Colombia).

	Dry seed yield (kg ha^{-1})	
Phaseolus genotypes	Single cropping	Association
Rionegro: relay cropping with maize[1] *(August 1993 to January 1994)*		
G 35099 (*P. coccineus*)	875b	1770a
G 35224 (*P. polyanthus*)	932b	1769a
ICA VIBORAL (*P. vulgaris*)[2]	146c	315c
Pasto: simultaneous intercropping with maize (October 1994 to April 1995)		
G 35544 (*P. polyanthus*)	6514.3a	3645.7a
G 35522 (*P. polyanthus*)	5978a	3057.7ab
G 35521 (*P. polyanthus*)	2981b	2874.7ab
G 35560 (*P. polyanthus*)	5724a	1840.bc
G 35516 (*P. polyanthus*)	2772.7b	1269.3a
BOLON ROJO (*P. vulgaris*)[2]	2894.9 b	1534.4c

[1]Beans sown at flowering period of maize; [2]best local variety used as a control.
Means followed by the same letter are not significantly different ($P < 0.05$).

resistance, compared with the heavily attacked control. In the same location, seed production of *P. coccineus* and *P. polyanthus* genotypes was higher in relay cropping than in single cropping. This can be explained by the good complementarity and lack of competition between maize and bean in such cultural conditions. In Pasto, most *P. polyanthus* improved lines outyielded the dry seed production of the *P. vulgaris* control in both single and intercropping. However, we observed a significant yield reduction of intercropped *Phaseolus* beans compared with single cropping. This reflects the strong competition between the two associated crops. However, farmers adopting this cropping pattern are usually more interested in the overall productivity and stability of the intercrop combinations, rather than in the seed production of each crop component. A good parameter to assess this overall productivity is the land equivalency ratio (LER), as described by Willey (1979). Preliminary results from Peru show an LER >1 for some maize–bean associations.

The interspecific lines were integrated in a recombination nursery, under single cropping and with the purpose of developing a large source population combining useful traits of *P. vulgaris, P. coccineus* and *P. polyanthus*. This recombination nursery was maintained for at least 4 years at the two stations of Rionegro and Chiquian. At each cultural season, we selected for the crossing block around 20–30 hybrid plants with complementary characters (particularly in terms of disease resistance, earliness in flowering, branching, seed production and harvest index) and a sample of the parental genotypes involved in the initial hybrids. In the case of cyclic recurrent selection (Chiquian), intermating was done each season between the most interesting interspecific individuals. In case of congruity backcrossing (Rionegro), hybrids were backcrossed alternately with the recurrent (*P. vulgaris*) and donor (*P. coccineus* and *P. polyanthus*) parents. In the recombination nursery, two major conditions were required in order to obtain progress in breeding interspecific hybrids. First, disease pressure had to remain high in the crossing block to keep genes of resistance from the donor species from one generation to the next. Secondly, intermating always had to involve parents having *vulgaris*-like and donor species-like characters. This was a prerequisite to broaden the genetic base of the improved populations, to avoid the rapid reversal toward the recurrent parent and to break undesirable linkage blocks present in either *P. coccineus* or *P. polyanthus*. One major difficulty in breeding interspecific hybrids was rupturing the linkage between high levels of resistance to *Ascochyta* leaf blight and some unfavourable traits, such as lateness in flowering, profuse branching and low harvest index.

Once good interspecific genotypes were identified, they were grouped according to similarity traits (mainly degree of branching, growth duration, seed size and colour, etc.) and submitted to mass, pedigree and bulk selection for 2–3 years. Such trials were first conducted on-station under relay cropping (Rionegro) or simultaneous intercropping (Chiquian). Later hybrid generations were tested in both on-station and on-farm trials, using only traditional intercrop combinations. In Peru, the breeding scheme adopted for the interspecific hybrids generated two improved composite populations from the combination (*P. coccineus* wild form × *P. vulgaris*) × *P. coccineus*: Bulk 1H and Bulk 2H. In first experiments made in Ancash and Lima Provinces, these two improved lines outyielded the *P. vulgaris* control (ANC-034 from Canario class), flowering 20 days earlier and giving a higher seed index (70–80 g 100 seeds^{-1} compared with 45 g 100 seeds^{-1} in ANC-034). The two lines also showed high field resistance to both anthracnosis and *Ascochyta* leaf blight. Bulk 1H and Bulk 2H are being tested in different small-scale farms of the Province of Ancash. For this purpose, we identified around 20 farmers interested in the improved varieties. As each variety represents a composite material, farmers are encouraged to practise their own selection and to modify their crop husbandry.

Conclusions and Recommendations

Our research on *Phaseolus* breeding is based upon a large genetic reservoir made of local germplasm stocks of two New World species (*P. coccineus* and *P. polyanthus*) and their crosses with *P. vulgaris*. The breeding outline follows the principles of a population improvement programme and leads to bulk varieties keeping sufficient genetic variation to cope with a traditional and heterogeneous agrosystem. The strategy is well fitted to breeding for multiple characters of both quantitative and qualitative inheritance and to developing varieties that combine good seed production, stress tolerance and competitive ability with the companion crops. In this process, small-scale farms can pick up improved populations with a broad genetic base from the breeding nurseries. This material has sufficient plasticity to respond favourably to various environmental constraints.

Success in breeding for intercrop combinations, however, requires several pre-conditions. These include availability of a large body of germplasm collection and hybrid populations, sufficient knowledge of the major agronomic constraints, good understanding of the yield components in relation to competitive ability, resources to breed at both on-station and on-farm levels and to adopt experimental layout mimicking traditional cropping systems. In order to upgrade productivity of intercrop combinations, any genetic changes among the component crops should also be accompanied by modifications in agronomic practices. The final objective will be not to disturb markedly a traditional cropping system but rather to open it up to other innovations. The ultimate impact of the research efforts will be the farm families themselves, which are faced with a need for food security and better income.

As stated before, the farming system approach will help to develop end-products that outperform existing varieties and are readily acceptable by the local populations. In this approach, on-farm trials are essential to back station-based investigations and to reorient the selection process according to the new constraints observed in a less uniform and more stressful environment. Testing in farmers' fields will also enable the selection of improved materials not only on the basis of yield but also on the basis of economic value, stability, total cropping system production or labour input.

The link between breeders, extension services and farmers is of course essential to achieve the breeding objectives. Such a close collaboration between these three should be financially supported by public agencies involved in agricultural research and integrated rural development.

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