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Aspects of participatory plant breeding for quinoa in marginal areas of Ecuador

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Summary Field trials were carried out in Ecuador with two indigenous communities, Ninín Cachipata and La Esperanza, to determine farmers' preferences for quinoa (*Chenopodium quinoa* Willd.) cultivars and to improve PPB processes. More women than men participated, reflecting that quinoa, a primarily subsistence crop, is mainly managed by women. Farmers' field selection criteria for quinoa in the field were mostly based on yield, earliness and plant colour; however only breeders' measurements of yield and panicle height significantly correlated to farmer selection scores. Older women gave higher scores than younger women or men, apparently due to a concept of no cultivar being without value. Working in same gender pairs improved evaluation richness. INIAP technicians were more discriminating in their evaluations than farmers. They also used additional selection criteria of disease resistance and uniformity. At seed selection, farmers from Ninín Cachipata, where food security is not assured, chose lines based on yield, while farmers from La Esperanza, where resources are less limiting, also considered seed size, colour, saponin content and marketability. Field characteristics were not taken into consideration at seed selection, signifying that farmers are less interested in those characteristics, or that it was difficult for them to correlate field data when presented in tabular form with seed characteristics. Future trials with small farmers should have fewer lines or replications to avoid farmer fatigue during evaluation. Farmers who grow primarily for subsistence in semi-arid environments have more interest in growing quinoa, and more to gain from having improved cultivars; therefore future participatory efforts should focus on them.

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Abbreviations

CGIAR	Consultative Group for International Agricultural Research

EESC	Estación Experimental Santa Catalina (Santa Catalina Research Station)
INIAP	Instituto Nacional Autónomo de Investigaciones Agropecuarias (the National Agricultural Research Institute of Ecuador);
PPB	Participatory plant breeding
PREDUZA	Proyecto de Resistencia Duradera en la Zona Andina (Project for Durable Resistance in the Andean Zone)

Introduction

Quinoa (*Chenopodium quinoa* Willd.), a pseudo cereal domesticated in the Andean region, yields a dry fruit containing high quality protein. It is adapted to arid, cold, high altitude ecosystems with low soil fertility (Fleming and Galwey 1995). For this reason, it is a useful crop in marginal low input environments.

Formal breeding of quinoa started in the 1960s. However, national breeding programs in Ecuador, Peru and Bolivia have been plagued by irregular funding, while the CGIAR has never targeted the crop for major improvement efforts. PREDUZA, a project supported by Wageningen University aiming to support Andean breeding programs, has been working on quinoa breeding in the region for the past eight years with emphasis on resistance in marginal areas. Recently, the McKnight Foundation has also begun supporting breeding efforts by the PROINPA Foundation in Bolivia.

While in the past 15 years quinoa, particularly organic quinoa, has become in vogue as an export crop for health conscious consumers of the North, it remains primarily of importance to low resource farmers in marginal environments cropping small areas where maize, barley or wheat perform poorly (Mujica 1992; Yépez 2001). As such, formal breeding focusing on releasing cultivars for wide adaptation using mechanized processes on large homogeneous high input areas is largely futile. With this in mind, PPB, initially developed for smallholder agriculture in difficult, diverse environments, appears to be a viable alternative for improving quinoa germplasm in poor farmers' fields (for review see Weltzien et al. 2000). PPB involves farmers and other stakeholders in the breeding process. Stakeholders may work with scientists in any of the five basic steps of the plant breeding cycle: setting goals, creating variability, selecting experimental lines/genotypes, testing experimental lines/genotypes, and cultivar release/diffusion.

Previous research in PPB points to the need to tailor the process to the particular crop and the capacities of farmer participants. The number of entries which farmers are capable of evaluating has differed from around 30 for potato (Thiele et al. 1997) to at least 208 in barley (Ceccarelli et al. 2000).

Advantages and disadvantages of on farm and on station evaluations have been discussed in previous PPB research. For example, on-station, the risk of crop failure is not carried by the farmer, but farmers who take the time to visit the station tend to be more interested in PPB (Weltzien et al. 1996). However, on-station crops are not in the same environment as the farmers' crops (Sperling et al. 1993). Also the differences in plant breeder evaluations versus farmer evaluations have been noted. Ceccarelli et al. (2001) observed technicians to be better evaluators of yield on-station, while farmers were better yield evaluators on-farm.

PPB research in other crops has found clear gender-related differences in evaluation techniques and criteria. Weltzien et al. (1996) noted that women's criteria in evaluating pearl millet were grain yield, early grain availability, and ease of hand harvesting, whereas men concentrated on the yield and quality of the straw. Kamara et al. (1996) found that female maize farmers in Mali focused on cooking aspects and men on yield and early maturity. Sthapit et al. (1996), in their research on rice in Nepal, discovered that men preferred to evaluate during the growing season while women chose to evaluate post harvest, and that evaluation characteristics differed.

Disease resistance brings up issues of particular interest for PPB. In research by Thiele et al.

(1997), farmers were observed to have some ability in recognizing disease and evaluating disease incidence. Other researchers have removed non-resistant breeding lines from trials either before or after farmers evaluated the trial (Sperling 1996; Zimmermann 1996). In quinoa, losses of 30% of the crop to downy mildew (*Peronospora farinosa* f.sp. *chenopodii*) in moderately resistant cultivars and up to 99% loss in susceptible cultivars have been reported (Danielsen et al. 2000).

The following describes the process and outcomes of introducing participatory varietal selection, an important form of PPB, to quinoa breeding for smallholder agriculture in the Ecuadorian highlands. Farmer participants were involved in evaluation of experimental quinoa lines. Objectives of the research were: (1) to tailor PPB evaluation techniques to quinoa and to Ecuadorian smallholder farmers, (2) to compare farmers' evaluation abilities on farm and on station, (3) to explore gender-related evaluation differences among quinoa farmers and how that could affect future PPB trials, and (4) to determine farmers' knowledge of quinoa disease and how that affects their evaluation abilities.

In addition to the above stated objectives, interviews with quinoa farmers were seen as vital to the PPB process, as formal breeding programs often fail in low resource, marginal environments because farmers' needs and preferences are not properly understood. The objective of the interviews was to place PPB techniques for quinoa breeding in the context of the local economy, agricultural practices and general lifestyle of the rural Ecuadorian highlands.

Materials and methods

Time and resource availability restricted our interviews to two communities, one in the village of Ninín Cachipata (Cotopaxi province, 3,300 m a.s.l.), and one in the village of La Esperanza (Imbabura province, 2,660 m a.s.l.). Those were small communities, as most communities are in the Andean highlands. Within those two communities, farmers were contacted for their willingness to take part in activities related to the field trial. Everyone who showed interest in collaborating was interviewed.

Case study farmers

The farmers who had shown interest in quinoa cultivation and improvement in previous interactions with researchers from INIAP and were currently growing quinoa or had done so in the past were selected for in depth case studies. In Ninín Cachipata, two men and three women were selected, in La Esperanza six women. Case study farmers were a subset of all farmers participating in the field trial, and were selected for their willingness to be interviewed, as well as being representative of the sex and age of farmers in that particular field trial.

Interviews were conducted over a period of four months. Visits occurred at farmers' homes or fields. Interviews were informal conversations. Themes were prepared before interviews, which also included additional themes brought up by farmers. Interview topics included: crops grown and livestock kept, seed origin, familiarity with quinoa cultivars, crop management (fertilizer use, intercropping, sowing density), disease and pest problems, importance of saponin content and seed colour, quinoa consumption, cost of production, and other income generating activities.

Field trial design and management

Farmers in both La Esperanza and Ninín Cachipata agreed to have an evaluation trial on their land. In each village as well as at EESC (3200 m a.s.l.), 20 quinoa breeding lines and the control cultivar INIAP-Tunkahuán were sown, thereby allowing the comparison of evaluations both on farm and on station. These lines, including 'INIAP-Tunkahuán', were based on accessions from the National Gene Bank (DENAREF). The selection of the 20 lines was based on evaluations of quinoa germplasm during the previous (2000/2001) growing season. Materials were characterized by a moderate level of resistance to downy mildew (*Peronospora farinosa* f.sp. *chenopodii*), early maturity, high yield and large seeds. Despite the selection the range of variation for some of the important characteristics was still fairly large;

downy mildew percentage from about 10 to about 50%, maturity in days from sowing from 158 to 186, yield in g/plant from below 10 to over 50, saponin content from 0.0 to 7.7 and 100 seed weight in g from 0.43 to 0.63.

The crop was managed jointly by farmers and researchers following local practice. The experimental set-up was a randomized complete block design with three replicates. Plots were two rows by four meters (Ninín Cachipata) or three rows by five meters (La Esperanza and EESC) with 0.6 meters between the rows. The seed rate used was 10 kg/ha at La Esparanza and EESC, and 12 kg/ha at Ninín Cachipata. No fertilizers were given, except in Ninín Cachipata, where a small amount of guinea pig and rabbit manure was applied. The EESC site was considerably more fertile and homogeneous due to its normal use for experiments.

Evaluations at flowering and after harvest

At flowering, farmers individually graded each plot within the trial as good, fair or bad and gave reasons for that score, which were recorded by the researcher. However, in addition to the individual evaluations, some pairs of farmers evaluated trials with the researcher.

Post-harvest evaluations were divided into three steps, all carried out on one day. First, farmers evaluated grain characteristics. Farmers evaluated one replication of threshed grain from 10 plants of each line. In each village, farmers chose as a group (in two groups in La Esperanza due to the larger number of participants) the six best lines based on their own perceptions of grain characteristics. As in the evaluation at flowering, farmers' reasons for choosing a particular line were given. Secondly, culinary attributes were examined for three of the breeding lines with differing saponin content, as well as for the local cultivar INIAP-Tunkahuán and a commercial brand of quinoa obtained from the supermarket. The cultivar of the supermarket quinoa could not be ascertained as the distributor purchases quinoa from various national and international sources. For this taste test, samples were thoroughly washed to remove all saponin, and then boiled. Each farmer tasted each of the five samples and gave opinions concerning cooking quality. Thirdly, farmers individually made their final selections of three lines for trials in the following season considering in principal the results from all of the evaluations. Data from the evaluations at flowering, in poster form, were also on hand to help them in their final selections, if they should like to use it.

The numbers of farmers participating in the various activities varied somewhat. In La Esperanza 11 farmers participated and seven where almost always present. At Ninín Cachipata 19 farmers participated with a core of seven always present.

Statistical analysis

Spearman rank order correlation was used to determine correlation between farmers' evaluation scores and physical measurements made by the researchers. The Mann–Whitney test was used to determine difference between evaluation scores between trials.

Results and discussion

Interviews

Farmers expressed interest in sweet (low saponin) quinoa, because low saponin quinoa does not require the tedious process of washing the grain to remove this detergent-like bitter compound. While INIAP had officially released two cultivars of quinoa with low saponin content in 1997 (Nieto et al. 1997), only one of the interviewed farmers had seed of sweet quinoa, the origin of which could not be identified. Farmers interviewed who lived nearby this particular individual expressed interest in sweet quinoa, but did not possess such cultivars themselves. This reveals that materials from INIAP's earlier quinoa breeding have not reached these villages. Also, spread of desirable seed is less fluid than one might expect, as farmers living near each other and who meet and talk every day do not share desirable quinoa germplasm. We did not determine if farmers are more inclined to share seed of other crops.

Farmers, especially in Ninín Cachipata, regard themselves as seed insecure, meaning there is a high likelihood that they do not produce sufficient seed in one year for the following year's sowing. Farmers mentioned crop failure as a common problem due to drought and frost, not only in quinoa, but also in other crops such as maize and potato. Farmers spoke of the need to replace entire stocks after crop failure by buying seed in the nearby market towns. Seed insecurity has implications for how farmers can select and maintain germplasm for their environment, as well as how access to improved seed suitable to their needs could be arranged.

Maize, potato and, to a lesser extent, legumes are the staple subsistence foods of both Ninín Cachipata and La Esperanza. Quinoa is generally intercropped with maize and common bean, with potato as a rotational crop. Fertilizer is usually applied only to potato, which is often grown in monoculture. Cash crops include potato as well as tomato and raspberry. Farmers were interested in the idea of growing quinoa as a cash crop, especially as many were disappointed about the previous season when the price for potato dropped below the cost of production. A common concern was the availability of markets and the economic gains to be made. Using a combination of farmers' own estimates of labour inputs, agronomist estimates of yield under low inputs, and the wholesale price offered by a quinoa processor and exporter in Quito (Ecuador's capital), the profits to be made by growing quinoa as a cash crop were calculated (Table 1). Farmers who grow quinoa in La Esperanza, where a manual day labourer earns US$ 5–7 per day, do not necessarily earn more than a labourer, and may earn less. In Ninín Cachipata, where day labourers earn less (US$ 3–4 per day), a quinoa farmer may earn 50 to 100% more than a labourer. A more complete analysis would include historical price data for quinoa and the availability of day labour employment. This type of conversation, venturing into markets and economics, is not the traditional terrain of a plant breeder. However, it may be more relevant to participatory quinoa breeding, and crucial for developing economically feasible seed propagation systems, but this is beyond the scope of this paper. Farmers' interest in PPB, and the nature of their participation and evaluations, is related to how they will use the crop. Facilitating farmer access to price information to guide their decisions about growing quinoa for subsistence or moving to commercial production, or even partaking in another economic pursuit, can in this light be considered part of PPB in a multidisciplinary approach.

Germplasm evaluations

Gender

Women showed more interest in quinoa farming, and consequently quinoa breeding, than men. Women were more ready to discuss at length

Table 1 Small producers' earnings in US dollars for quinoa farming in two locations of the Ecuadorian highlands

Estimated salary working as a labourer	$3–4/day[a] (Ninín Cachipata)	
	$5–7/day (La Esperanza)	
Estimate of total work days required to produce 1 ha of quinoa[b]	100–130 days	
Selling price for quinoa (not certified organic) in 2002[c]	$0.64/kg	
Estimated yield potential for quinoa grown under semi-arid conditions[d]	Without fertilizer	After crop of fertilized potato
	900 kg/ha	1300 kg/ha
Gross earnings for sale of 1 ha of quinoa	$576	$832
Earnings per day of quinoa farming labour	$4.50–5.80	$6.40–8.40

[a] Salary is farmers' estimate of earning power, and is in agreement with salaries paid by INIAP to field labourers in 2001–2002

[b] Low estimate is from INIAP agronomist, high estimate is from farmers

[c] Wholesale price paid by Inagrofa, SCC, a quinoa processor, in 2000–2001 growing season

[d] Estimates by agronomist with extensive experience in quinoa production

[e] As small farmers do not usually use fertilizer or other inputs in quinoa production, entire gross earnings can be applied to labour

quinoa and quinoa breeding then men, who often wished to change the topic of conversation. Women also expressed their interest by showing up more readily for field work and evaluations at the field trials, and taking more time in their evaluations. While it is true that in the two communities involved there were more women than men actively farming, the men who were actively farming showed less interest than women. Quinoa, as a crop mainly used for household consumption, is considered as women's responsibility rather than men. Men are occupied more with earning cash income. As such, it is not surprising that women were the more active participants.

Women, particularly older women, tended to give higher scores in evaluations than men. Women gave significantly higher scores than men for four lines of quinoa and the mean overall score given by women was higher than that given by men, even excluding those four lines (Table 2). There was a certain unwillingness by women to give a score of 'poor' to a line. This did not mean that women were less observant or critical than men. Specific comments on a particular plot showed that women were able to point out what was preferable about a plot and what was not. Lack of experience in quinoa cultivation was not a hindrance for either sex. Nor was a clear

Table 2 Differences observed between evaluations of quinoa lines at flowering[a] by farmers of two communities on farm and on station, by male and female farmers, and by technicians and farmers

Line[b]	Ninín Cachipata[c]			La Esperanza[c]			Gender differences[d]		Technicians vs. farmers[e]	
	On farm	On station	Yield[f] (g/10 plants)	On farm	On station	Yield (g/10 plants)	Female	Male	Technicians	Farmer
ECU-228	*2.2	2.9	33	2.3	2.0	117	2.2	2.0	3.0	2.5
ECU-234	2.5	2.9	61	2.6	2.1	363	2.6	2.2	2.0	2.5
ECU-239	*2.1	2.6	48	2.5	2.3	–	2.4	2.5	1.5	2.5
ECU-244	2.6	2.9	82	*1.6	2.7	111	1.7	1.5	1.8	2.5
ECU-271	*1.5	2.6	36	2.3	2.0	58	2.2	2.1	1.5	2.4
ECU-284	2.7	2.6	73	2.0	2.4	79	2.4	1.5	2.0	2.5
ECU-286	*2.1	2.5	60	2.6	2.6	57	2.7	2.5	2.3	2.6
ECU-287	2.6	3.0	50	*1.6	2.7	120	*1.9	1.0	1.8	2.6
ECU-294	*2.5	2.9	66	2.9	2.9	214	*3.0	2.5	2.3	2.9
ECU-298	*2.2	2.6	47	*1.3	2.3	53	1.4	1.5	1.8	2.6
ECU-315	2.2	2.9	59	2.5	2.3	194	*2.6	2.0	1.8	2.5
ECU-317	*2.3	2.9	61	3.0	2.6	196	2.8	3.0	2.0	2.7
ECU-321	*2.0	2.8	31	2.3	2.7	116	2.3	2.0	1.8	2.8
ECU-338	*2.0	2.4	40	1.9	2.4	88	1.9	2.0	2.0	2.6
ECU-359	2.3	2.4	78	*2.6	1.3	185	2.5	2.6	1.3	1.8
ECU-524	2.4	2.2	39	2.5	2.3	70	2.6	2.5	1.5	2.3
ECU-544	2.6	2.5	38	2.3	2.0	45	2.5	2.0	1.8	2.3
ECU-572	2.8	2.3	99	2.5	2.7	18	*2.7	2.0	2.5	2.5
ECU-580	2.0	2.1	54	2.5	2.0	202	2.5	2.5	1.0	2.0
ECU-585	2.7	2.3	85	2.9	2.9	57	2.8	2.5	2.0	2.6
Control[f]	2.9	3.0	116	2.5	1.9	152	2.5	2.0	1.5	2.4
Mean	2.4	2.6	–	2.3	2.3	–	2.4	2.1	1.9	2.5

[a] Lines were scored on a scale of 1–3, with 1 = poor, 2 = regular and 3 = excellent

[b] Identification number in the Ecuadorian national collection

[c] Score is the mean of values assigned by seven farmers from the community. Scores marked with an * are significantly different between on farm and on station evaluations according to the Mann–Whitney test ($P \leq 0.05$).

[d] Score is the mean of values assigned by 11 female and five male farmers from both Ninín Cachipata and La Esperanza evaluating at EESC. Scores marked with an * are significantly different between female and male evaluators according to the Mann–Whitney test ($P \leq 0.05$).

[e] Evaluations at EESC. 14 farmers and two technicians evaluated

[f] The control was INIAP-Tunkahuán

difference discernible between selection criteria based on the gender of the evaluator, in contrast to PPB research in other crops. However, women's dislike of calling any quinoa line 'poor' may relate to a concept of no crop being worthless, no matter how sickly. In the windy, cool, arid environment of the highlands, any plant which grows can provide some nutrition or use, and women may feel reluctant to disregard that. Men, more attuned to commercial pursuits and less directly involved in feeding the household, may not feel this same relationship to the crop.

An evaluation system with more than three grades may make it easier for women to differentiate between how much they like a particular breeding line by eliminating the need to label any as 'poor' or useless. Also, as men tend to dominate the conversation in mixed groups, it would be useful to maintain separate evaluation groups, as Weltzien et al. (1996) found to be a solution as well. It may be useful to focus further PPB efforts on women or women's groups, as women were more eager to collaborate. However, should quinoa become more of a commercial crop, men may wish to take a more active role as well.

Evaluation at flowering

Farmer's reasons for giving high marks to a particular plot included (from most to least frequently mentioned): Visual estimate of yield, earliness, plant colour, plant height, robust foliage, uniformity, and ramification (Table 3). Reasons for low marks included thin stems, non-domesticated appearance, evidence of diseases/pests, and visual estimate of high saponin content. Farmer evaluations significantly correlated to breeder measurements of yield ($r_s = 0.67$) and panicle height ($r_s = 0.55$), corroborating that yield estimates where primarily of importance for their evaluation. Measurements of plant height, days to harvest and uniformity did not correlate significantly to farmers' evaluations.

Farmers became fatigued after evaluating three replications of 21 plots. The degree of visual similarity between lines may have an effect on the number of lines farmers can evaluate. The more similar the lines, the more tedious comparison becomes and the fewer lines farmers can evaluate. Farmers found it easier to converse about characteristics of the crop among themselves, bringing out richer observations than when relating their evaluations to a researcher only. A future improvement may be to have three non-replicated trials in one village. Then the farmer and a colleague could evaluate only the materials on their trial, avoiding fatigue but still maintaining replications for statistical analysis.

Heterogeneity in farmers' fields

Soil fertility in Ninín Cachipata was quite heterogeneous. This is probably due to the uneven spread of animal manure on the field, as it is the common practice to put guinea pig manure on the field when cleaning the hutches, and the side of the field closest to the hutches was more fertile. This caused some plots to be exceedingly verdant, while other plots had quite yellow, sickly, nitrogen-deprived plants. Farmers noted this in their evaluations, making statements to the effect that the particular accessions would probably look better if they had more fertilizer.

Heterogeneity in farmers' fields is common. So, a well-adapted cultivar should perform well under a variety of conditions that are common in farmers' fields. Therefore it may be interesting if this heterogeneity is put to use in future field trials, rather than attempting to avoid it. Breeding materials that do well in both low and high soil fertility conditions show themselves to be less dependant on high inputs and perhaps more broadly adapted than a line which is adapted to high or low inputs only. In fact, trials which are purposefully placed in sites with abiotic stresses (cold, wind, aridness), as suggested by Bänziger and Cooper (2001), would be more useful for selecting materials with tolerance to those conditions than by avoiding such sites. Making use of this heterogeneity would increase the number of trial sites and hence the demand for seed for future work of this nature.

Comparing farmer and technician evaluation criteria at flowering

INIAP technicians evaluated quinoa plots at flowering based on visual estimates of yield, uniformity, and compactness of panicle, earliness,

Table 3 Individual farmers' criteria for quinoa breeding lines evaluated in their communities and at the EESC

Evaluation criteria[a]															
Site[b]	Farmer gender	High yield	Early	Color of plant[c]	Tall plant	Green foliage	Uniform	Good windbreak	Large grain	Ramified	Bitter seed	Weedy	Disease/ plagues	Thin plant	Leafy
NF	F	+	+		+								–		
	F	+	+	P	+										
	F	+	+		+	+	+						–		
	F	+		P	+	+									
	M	+	+	P	+	+									
	M		+/–		+										
	M	+		P	+	+	+			+					
NS	F	+													
	F	+		P										–	
	F	+	+	P	+	+	+							–	
	M	+		P	+			+			–				
	M	+	+	G	+							–		–	
	M		+	G	+									–	
LF	F	+	+	P	+						–				
	F	+	+		–										
	F	+	+/–		+						–				
	F	+	+	P					+			–			
	F	+	+	P		+			+						
	F	+	+												
	M		+	P											
	M	+			+/–										
LS	F	+	+	P	–		+							–	
	F	+	+	P	–		+								
	F	+	+	P						+/–				–	–
	F	+		P								–			
	F	+	+							+/–				–	
	M	+	+		–										
	M	+	+												

[a] + indicates the trait is desirable; – indicates the trait is not desirable

[b] Evaluations occurred within the farmers' own communities of Ninín Cachipata and La Esperanza and at EESC: NF = Ninín Cachipata on farm, NS = Ninín Cachipata on station, LF = La Esperanza on farm, LS = La Esperanza on station

[c] P indicates farmer preferred pink or purplish coloration of the plant; G indicates farmer preferred green plants

height, disease resistance, and thickness of stem. The major difference between technicians' and farmers' evaluation criteria is that technicians gave lower scores, and the importance of plant colour, uniformity, and thickness of the stem differed (Table 2). Farmers' preferences at flowering were influenced by colour. Most farmers found plants with pink leaves more appealing. This may be due to lack of other agriculturally useful differences (in their eyes) available at this stage. Technicians did not consider plant colour as an important parameter. Technicians' interest in stem thickness is based on mechanical threshing, which is easiest when the stem is neither too thick nor too thin. Farmers threshing by hand had no such concern. Also, it should be noted that farmers did not dislike heterogeneous lines and were not particularly concerned with that aspect. Perhaps for farmers with more quinoa market experience, uniformity is more important. However, as farmers from these communities have produced quinoa almost exclusively for home consumption, market-oriented selection criteria are not expected. This could change, should quinoa evolve into a crop with more commercial interest for them.

Plant breeders are concerned about the level of downy mildew resistance in quinoa lines. However, farmers were not aware of downy mildew as a particular disease affecting quinoa. They are aware of and concerned about other plant diseases, such as late blight (*Phytophthora infestans*) of potato. However, the yellowing and wilting of leaves caused by downy mildew infection was not considered by farmers to be caused by a disease. Rather, farmers viewed it as a natural part of the plant life cycle, as it is the older leaves which show more damage. If ample disease pressure from a complex *Peronospora* population were always present in trials, this would not be problematic, as farmers, selecting for high yield, would naturally choose tolerant or resistant quinoa lines. As this is not always the case, in this context best practice would be for plant breeders to ensure that materials used in on farm trials have already shown a reasonable level of resistance.

While technicians consider homogeneous lines a sign of genetic uniformity, this may not be what performs best in a highly heterogeneous, risky environment. Having more genetic variability in the field can be a way of avoiding the very real risk of total crop failure (Brouwer et al. 1993). Of course, genetic variability may also be gained by mixing cultivars in the field, for instance.

On-farm versus on-station trials

Evaluation scores on-station differed significantly ($P \leq 0.05$) for nine accessions compared in the Ninín Cachipata trial and four accessions compared in the La Esperanza trial (Table 2). Except for one case, all accessions were evaluated more favourably on-station than on-farm. This result is not surprising, as climate, soil fertility, and management were more favourable at EESC. On-farm trials had low, heterogeneous soil fertility and were arid, as is typical of smallholders' fields. On-station trials were characterized by high soil fertility and optimum management practices. Farmers visited the research station only once, while farmers were able to visit the on-farm trial frequently, meaning that the evaluations on farm could be not only more representative of farmers' conditions, but perhaps also more economic. However, since neither scores nor physical measurements were similar for the two situations, it would be unwise to substitute on station trials for on-farm trials in the future, as the risk of selecting materials unsuitable to on-farm conditions is great, even if farmer preferences are known.

Evaluation of seed

Ninín Cachipata farmers evaluated grain almost entirely on yield (Table 4). Their top four choices were also the top four in grain yield. La Esperanza farmers evaluated seed considering seed colour, seed size, probability of it being sweet due to plant and seed colour, and grain yield. Neither group considered evaluations at flowering when choosing their seed for the next year.

It is remarkable that field evaluations were not taken into account for choosing seed for the trial of the following year. The question is whether those characteristics were really less important. If so, than there would be no need to spend resources on field evaluation. However, the accessibility and intelligibility of the data for

Table 4 Lines selected from those mentioned in Table 3 and their characteristics assessed in Ninín Cachipata and La Esperanza

Line	Yield rank at site[a]	Saponin content[b]	Seed weight (g/100 seed)	Farmers' reasons for selection[c]
Ninín Cachipata				
Tunkahuán[d]	1	0.0	0.27	High yield, white, sweet, large seed, easy to cook.
ECU-585	3	0.0	0.27	High yield, white, sweet, round seed.
ECU-244	4	1.9	0.29	High yield, white, large seed.
ECU-572	2	0.3	0.25	High yield, sweet, yellow.
La Esperanza-group 1				
Tunkahuán	7	0.0	0.28	White, large seed, looks sweet, good yield, easy to wash.
ECU-317	4	5.0	0.31	Clean, large seed, creamy color, looks sweet.
ECU-244	11	1.9	0.29	Large seed, creamy color, looks sweet.
ECU-585	16	0.0	0.20	White, round, small seed, attractive grain.
La Esperanza-group 2				
Tunkahuán	7	0.0	0.28	White, large seed, looks sweet.
ECU-234	1	4.3	0.30	High yield.
ECU-294	2	5.5	0.29	Large seed, medium white color, high yield.

[a] Lines were ranked for yield separately in La Esperanza and Ninín Cachipata, from highest to lowest yielding

[b] Measured in cm foam formed after vigorously shaking 0.5 g seed in 5 ml water in a 100 ml diameter test tube for 30 s, with more foam indicating more saponin

[c] Reasons for selection are combined from the entire group of farmer evaluators

[d] The cultivar INIAP-Tunkahuán was the control

farmers may have played an important role. Evaluation data from the field, when plants were flowering, were made available in a table and were hence far less easy for farmers to interpret than seed data, which could be directly interpreted. Most likely, the farmers were not familiar with interpreting these paper data. Plant breeders have developed specialized methods for managing data. Farmers have not and will therefore need different types of methods to help them manage data. Farmers use visual differences to distinguish lines and associated characteristics rather than breeders' use of written records to manage data.

Economic aspects may account for the differences between Ninín Cachipata choosing their seed samples based almost purely on yield, while La Esperanza considered various other characteristics, such as colour, seed size and shape and perceived sweetness. The case studies revealed that La Esperanza residents have on average a much higher cash income than Ninín Cachipata. Evidence of this is seen in the greater presence of electricity, mobile phones, televisions, and purchased foodstuffs. Case study farmers reported that this is due not only to a milder climate and access to water, but also to La Esperanza farmers having family members, mostly male, sending remissions from abroad. While farming styles remain more or less similar, with the exception of the use of hired ox teams in La Esperanza for ploughing, the reliance on agriculture for subsistence is reduced. Therefore La Esperanza farmers worry les about having an adequate food supply. They can be more critical in choosing food based on grain colour, seed size, and saponin content, with yield as a still important, but secondary factor.

There is a notable discrepancy between interview results and seed evaluation results. Almost all farmers complained about the large amount of work needed to wash quinoa. However, low saponin cultivars of quinoa need very little washing. The farmers did not remark on the need to improve yield during interviews. Yet, at seed evaluation, one community does not take into consideration saponin levels at all, while the other treats it as one of several factors. Is this, again, because saponin levels are less visible? They can be roughly evaluated by tasting the raw grain, so it was possible for farmers to test it at seed evaluation without relying on tabular data.

In the future, it may be preferable to work with farmers who have less resources at hand than those of La Esperanza. While farmers in La Esperanza grow quinoa, they are not particularly interested in it as a crop, as they have more resources at hand from other economic activities. For farmers with fewer options and in harsher conditions, quinoa may make a real difference in the total harvest and the subsequent nutrition level.

Taste test

After washing and cooking quinoa, the level of saponin in the unwashed grain was irrelevant to taste. However, line ECU-544 left a bitter after taste which farmers did not believe was caused by saponin. Also, while farmers are generally pleased with the raw grain colour of INIAP-Tunkahuán, after cooking some felt it became too yellow. This shows that cooking trials form an important part of the evaluation procedure, as this information is not available otherwise.

It should be mentioned that in Chimborazo province over 600 tons of organic quinoa are produced annually for export by approximately 3,600 families pertaining to ERPE (the *Escuela Radiofónica Popular de Ecuador*). The cultivar INIAP-Tunkahuán is not popular among those farmers due to its poor adaptation, low yield and sweet taste. Quinoa producers in this area prefer a traditional cultivar with a bitter taste that helps to protect it against bird damage (J. Pérez, ERPE, personal communication). This demonstrates that selection criteria and preferences may vary and depend on location, type of farmer, use of the grain and market demand.

Field evaluation versus seed evaluation

As farmers were able to estimate yield fairly accurately at flowering, it is not vital that yield is evaluated at harvest. Also, in the field, farmers could make a better guess of whether some other factor, such as heterogeneous soil fertility or low density sowing, was affecting the yield and compensate for this in their evaluations. Earliness, uniformity, plant colour and plant architecture can only be known from field data. On the other hand, saponin content, seed size and seed colour are only possible to determine after harvest. As mentioned above, there is a certain discrepancy about the relative importance of these characteristics to farmers, which needs to be resolved. Therefore at this stage it is still advisable to evaluate both in the field and post harvest.

Future work and conclusions

Several conclusions can be made based on this research. With respect to using PPB for smallholder quinoa breeding in Ecuador, we find that several adjustments specific to the crop and culture are necessary. Smaller numbers of replicates are easier for farmers to evaluate meaningfully than has been encountered in PPB processes for some other crops. Evaluations processes should be as tangible and visible as possible, with limited use of tabular data. Farmers are able to contribute richer observations in pairs or groups, rather than with only a plant breeder. On-station evaluations were found to be of limited usefulness for this cropping situation, as on-station conditions poorly mimic field conditions, resulting in wide variation between the performance of individual lines on-station and in on-farm trials. Additionally, on-station evaluations were inconvenient for farmers, due to time, expense and hassle. Gender differences did play a role in farmer's evaluations. While both men and women were able to make informed observations of quinoa breeding materials, women did not want to categorically dismiss any lines. This difference can be allowed for in future PPB evaluations. Farmers' knowledge of quinoa diseases (specifically downy mildew) was limited. Disease resistance as such was not taken into account by farmers during evaluations; therefore any breeding program with the goal of introducing resistance will need to address that issue in a manner complementary to farmer evaluations.

This research addressed several questions which could benefit from additional investigation. The apparent lack of seed sharing and germplasm flow indicated during the interviews is puzzling. A more thorough look at the seed systems of the area may explain this, since seed sharing is often a mechanism to overcome seed insecurity, particularly when this occurs across different ecological floors which face different abiotic hazards. It seems that seed sharing would therefore be quite useful for low resource farmers of the Ecuadorian highlands as well, and perhaps it occurs in a manner which this research did not uncover.

Improvements in the seed evaluation methodology, reduction in the number of lines, and an evaluation scale with more values should also enhance researchers' ability to communicate effectively with farmers. This may also resolve discrepancies appearing in the interviews and the evaluations concerning the relative importance of low saponin cultivars versus yield.

This research was a valuable step towards developing PPB methodologies for quinoa. Farmers' interest was apparent. Information on how gender differences and economic status can affect results was found and can be used to improve the methodology as well as giving information on what types of communities and participants should be targeted for further trials. The specific criteria where farmers and plant breeders are likely to differ in their evaluation scores became clear, which allows plant breeders to rethink the way in which they evaluate. Data gathered on the individual lines of the trial can be used to plan further trials, as in any plant breeding experiment. A further benefit is that plant breeders became more accustomed to interacting with farmers as collaborators in technology creation, rather than just recipients of liberated cultivars.

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