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ASSESSING THE BENEFITS OF ANDEAN CROP DIVERSITY ON FARMERS' LIVELIHOOD: INSIGHTS FROM A DEVELOPMENT PROGRAMME IN BOLIVIA AND PERU

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Abstract: This paper analyses the impact of a development programme designed at promoting the sustainable use of Andean Grain diversity. Results demonstrate that knowledge-sharing on agronomic practices, on benefits derived from consumption, and improving Andean Grain quality had a positive impact on income generation and farmer livelihoods. These results demonstrate the effectiveness of programmes aimed at improving rural livelihoods through greater knowledge transfer and use of local agrobiodiversity, wherein private benefits may incentivise the public benefits of agrobiodiversity use and conservation. Findings warrant the need to further monitor and evaluate the potential of agrobiodiversity to improve the well-being of rural communities. © 2017 The Authors *Journal of International Development* Published by John Wiley & Sons Ltd.

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1 INTRODUCTION

Farmers worldwide have made use of natural resources for their survival and livelihoods for thousands of years, most notably through the strategic use of plant and animal biodiversity, breeding thousands of varieties of plants and animals in order to face a range of environmental and agricultural challenges (Frison, Cherfas, & Hodgkin, 2011; Mijatović, Van Oudenhoven, Eyzaguirre, & Hodgkin, 2012). The broadening of the plant variety portfolio has allowed farmers to successfully sustain food production over time, enabling them to adapt to changes in agricultural systems (Baumgärtner & Quaas, 2010; Howden *et al.,* 2007; Cavatassi, Lipper, & Narloch, 2011), diversify their incomes (Bellon, 2004) and improve their diets and overall livelihoods (Thrupp, 2000; Nabahungu & Visser, 2011; Gotor, Caracciolo, Canto, & Al Nusairi, 2013; Bellon, Gotor, & Caracciolo, 2015b).

Through the centuries, marginal farmers in the Andes mountains have selected and bred different varieties of grains, such as quinoa (*Chenopodium quinoa*), cañahua or kañiwa (*Chenopodium pallidicaule*) and amaranth (*Amaranthus caudatus*) because of their strategic role in sustaining their livelihoods and food security (NRC, 1989; Holle, 1991; Jacobsen *et al*., 2003; Jacobsen, 2011).

Nevertheless, in the 1970s, these species were largely substituted by more profitable crops, and their role as a staple food started to decrease dramatically, with grains like quinoa in danger of disappearing by the early 1980s (Giuliani, Hintermann, Rojas, & Padulosi, 2012). Staples such as wheat, rice and maize-based foods have rapidly replaced traditional Andean grains. The reduced overall demand of Andean grains has been accompanied by the loss of their genetic diversity, with important, albeit less obvious, repercussions for the resilience of Andean communities. The decline in traditional grains has reduced options for farmers, particularly the poor (Padulosi *et al.,* 2014). The cultivation of traditional grains has become increasingly uncompetitive compared to major commodities, hampered by a lack of improved varieties, arduous cultivation practices, difficulties in processing, poor access to markets and the negative perception of these grains as 'food for the poor' (Giuliani *et al.,* 2012). This also had a detrimental impact on agricultural biodiversity in the region—an asset that is crucial to maintaining the ability of crops to adapt and evolve to changing environments, such as increasing climatic variability, new diseases (Plata & Gandarillas, 2014), pests (Saravia, Quispe, & Crespo, 2014) and parasites (Jacobsen, 2011).

However, in recent years, quinoa and other Andean grains have attracted renewed interest. An increased demand for Andean grains—especially quinoa, and particularly in the European market—for their nutritional value led to a boom in cultivation, particularly in Bolivia and Peru. While this shift represents a great short-term economic opportunity, this increased production is not necessarily sustainable in the long term. Management practices for the cultivation of the grain too often ignore crop rotation, and the new market opportunities do not necessarily improve the long-term livelihoods of the smallholders (Blajos, Ojeda, Gandarillas, & Gandarillas, 2014). Indeed, the intensification in production has narrowed down the portfolio of Andean grain diversity, making production systems more vulnerable to biotic and abiotic stresses, and has also reduced the nutritional opportunities linked to quinoa intraspecific diversity (Jacobsen, 2011). The result is a classic 'tragedy of the commons' situation wherein the private, short-term incentives go against the sustainable use of Andean grains and their genetic resources, instead favouring activities that could deplete the resource altogether (Drucker, Gomez, & Anderson, 2001; Gotor, Caracciolo, & Watts, 2010; Bellon, Gotor, & Caracciolo, 2015a). This has raised reasonable concerns about social and environmental sustainability,[1] suggesting that external intervention to obtain an optimum level of use for these crops may be necessary (Bezabih, 2008; Jacobsen, 2011).

Recent research initiatives have in fact demonstrated that the inclusion and the successful management of native species are key factors in promoting the sustainability of production systems based on Andean grains (Bonifacio *et al.,* 2014). Interventions need to be grounded in appropriate, multidimensional mechanisms insofar as they face a dynamic system characterised by continuous interactions between economic, social and environmental forces (Bellon *et al.,* 2015a). As a consequence, the evaluation of the efficacy of interventions is itself extremely complex, not only for the multidimensionality of the expected outputs (genetic resources conservation, ecosystem services, private benefits), but because the results may vary nonlinearly depending on time, space and scale (Limburg, O'Neill, Costanza, & Farber, 2002). Indeed, it is likely related to this complexity that while there exist many different types of interventions for supporting crop conservation and use in the world, as revealed by Jarvis *et al.* (2011), there is still little evidence of their effectiveness (Lutz & Munasingheb, 1994) with the few existing evaluation studies still failing to recognise and understand this complexity (Gotor & Irungu, 2010; Bellon *et al.,* 2015a).

The aim of this study is to fill this gap by adopting a recent theory-based approach (Bellon *et al.,* 2015a) in order to provide empirical evidence about the likely intervention pathways of a research-for-development programme designed to promote the sustainable use of Andean grain diversity in four regions within Bolivia and Peru. Participation in programme activities, knowledge-sharing, training in agronomic and processing practices, new modes of consumption and value creation are essential steps for achieving tangible outcomes: well-informed and trained farmers can improve their income and livelihood opportunities while contributing to the conservation and improvement of the resources they have access to (Nabahungu & Visser, 2011; Gotor *et al.,* 2013; Bellon *et al.,* 2015a). Because this paper faces the common problems of ex-post evaluation studies with non-experimental design (neither baseline information nor *a priori* controls exist) (Lewis *et al.,* 2011), a propensity score-matching and doubly robust estimator methodologies were used to assess the impact of rural households' participation in the programme. Programme impacts at household level were assessed, estimating the causal relation between participation in the programme and expected outcomes of the programme (i.e. households' well-being). This analysis was performed by comparing the outcomes experienced by households that participated in the programme activities with a counterfactual experience of a control group drawn from households that did not participate.

This evaluation recognises that a key aspect of the development efficacy is the sustainability of the impact (White, 2005). The latter is fundamental for understanding and evaluating the long-term efficacy of interventions and their association with rural livelihood resilience (Bellon *et al.,* 2015a).

The programme activities and its major outcomes are explained in section two of this paper. The description of the data collection process is in section three, while sections four and five describe the empirical framework used and results generated. The paper ends with a discussion of the results and their implications.

[1]For instance, expansion of the agricultural production area of quinoa in Bolivia has been implicated as the cause of degradation of soils and their ability to deliver ecosystem services (Jacobsen, 2011).

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Figure 1. Project sites distribution [Colour figure can be viewed at wileyonlinelibrary.com]

2 DESCRIPTION OF THE PROGRAMME

The development programme on Andean grains analysed in this paper was implemented over a period of 10 years and specifically includes two interrelated phases (2001–2005 first phase, and 2007–2010 second phase). The programme was a part of a larger framework of multi-country research projects supported by the International Fund for Agricultural Development. The projects were implemented in Latin America (Bolivia, Peru, Ecuador), South Asia (India, Nepal) and North Africa (Egypt, Yemen), and emerged from the need to test out a more comprehensive approach in conserving and sustainably using a complete pool of target crop genetic diversity within a livelihoods framework. In order to be effective and have a sustainable impact on people's livelihoods, the programme needed to be based on holistic approaches, be highly participatory, apply gender-sensitive interventions and pursue inter-disciplinary collaboration (Padulosi & Hoescle-Zeledon, 2004).

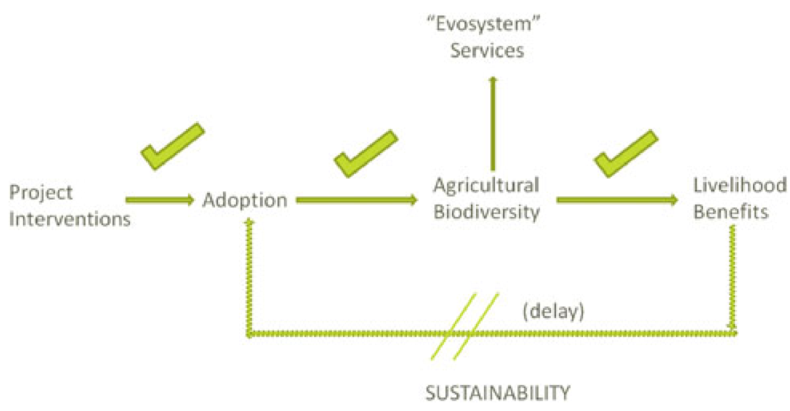
This study focuses on the Latin American component, and on Bolivia (La Paz and Chuquisaca) and Peru (Puno and Cuzco) in particular. The species quinoa (*C. quinoa*), cañihua (*C. pallidicaule*) and amaranth (*A. caudatus*), and target sites (La Paz and Chuquisaca in Bolivia, and Puno and Cuzco in Peru) were identified through a series of multi-stakeholder workshops undertaken in 2000. The target sites were carefully chosen for being representative of the agro-climatic situations faced by target species in different socio-economic, cultural and geographic contexts. Furthermore, the selected sites were also diversity hotspots for the different targeted species (Figure 1).

The department of La Paz holds a wide diversity of ecological regions, from high mountains and high flat lands close to the Eastern split of the Altiplano region, to inter-Andean valleys and tropical rainforest areas. The target sites in La Paz were the communities of Santiago de Okola, located on the northeastern banks of Lake Titicaca, and Coromata Media, located south of Lake Titicaca in the high Altiplano flatlands. These communities stand at an average altitude of 3800 to 4000 masl and are climatically influenced by Lake Titicaca, thus holding a wide diversity of native species. Santiago de Okola produces several species of native roots, tubers and grains and particularly quinoa, amongst other introduced species. Coromata Media, on the other hand, stands higher in altitude and thus produces native potatoes and Andean grains, particularly cañihua.

The target sites in Chuquisaca were the communities of Cuevas Cañadas and Mojotorillo, located on the foothills of the main Andean mountain chain. The department of Chuquisaca has the highest levels of chronic poverty in Bolivia, concentrated in rural areas. It is located in centre south of Bolivia, is traversed by the main Andean mountain chain and partly lies within the Amazon River basin. The valley weather in these communities enables them to produce diverse species and varieties of tubers, roots, chillies, beans, groundnuts, maize and amaranth.

The department of Cuzco in Peru is characterised by several life zones and microclimates ranging from highlands over 6000 m in altitude to the low jungle in the Amazon. Cuzco houses the eastern slopes of the Andes, a region that is extremely rich in biodiversity. The target sites in Cuzco were Auquiorko, located in the sacred valley of the Incas, and Occoruro, also a valley. The weather in this region enables the production of native species of maize, roots, tubers and amaranth among others.

Finally, in the department of Puno, both highly developed and underdeveloped areas coexist, with poverty incidence set higher among Andean indigenous communities. The Puno region of southern Peru has one of the highest poverty rates in the country, as well as high rates of child malnutrition. Given the area's harsh climate, farming is difficult and practiced mainly on a subsistence level. The target sites in Puno were Cieneguillas



Source: adapted from Bellon et al., (2015a)

Figure 2. Conceptual framework, the effectiveness of an on-farm conservation programme. Source: adapted from Bellon *et al.* (2015a) [Colour figure can be viewed at wileyonlinelibrary.com]

and Corisuyu, located near the western banks of Lake Titicaca, on the high Altiplano flatlands. The Peruvian–Bolivian Altiplano is part of the Titicaca basin, with average altitudes of 3800 m. Floods and droughts are common in different times of the year, the former during seeding season and the latter in the harvesting season.

This programme followed a holistic framework aimed at developing new methods, approaches and tools to address issues across the value chain of target crops and to bridge the gap between conservation and use (Padulosi *et al.,* 2014). Activities spanned from: (i) conservation and use of genetic diversity; (ii) promotion of good agronomic and processing practices; (iii) development of new modes of consumption and (iv) value creation and enhancement of public awareness on the importance of Andean grains, encouraging household knowledge exchange. By pursuing all of these activities together, the programme aimed to improve income generation, leverage the nutritional benefits of target crops and contribute to the sustainable conservation of genetic resources.

Effectiveness of the interventions with respect to providing relevant and sustainable conservation and livelihood results is here evaluated following the theoretical route outlined by Bellon *et al.* (2015a). According to Bellon *et al.* (2015a), an effective and sustainable on-farm conservation programme has to fulfil three interdependent goals: (i) to increase diversity; (ii) to establish a pathway between on-farm diversity and livelihood benefits, through the adoption of specific interventions that provide farmers with options aimed at changing the way they access, manage, use, perceive, consume and/or market crop diversity (iii) that in turn encourage farmers to conserve diversity. This chain of events creates a feedback loop that ensures both diversity and its continuing benefit to present and future generations in terms of 'evosystem services'[2] (Faith *et al.,* 2010) (Figure 2). Consequently, any empirical assessment of the effectiveness of the programme should verify its impact on dimensions significant to this pathway. This work provides a new application of the empirical framework described by Bellon *et al.* (2015a).

[2]By using the term 'evosystem' Faith *et al.* (2010) refer to evolutionary system. Consequently, 'evosystem' services were defined as 'all of the uses or services to humans that are produced from the evolutionary process' (Faith *et al.,* 2010).

As well described by Padulosi *et al.* (2014), several interventions were implemented in the context of the programme: farmers' fairs, crop diversity and use contests, and the introduction of new varieties of Andean grain sought to encourage genetic diversity. Six new improved varieties of quinoa and cañahua were introduced (among these, two free saponin varieties of quinoa and short-cycle varieties of cañahua).

Improved cultivation practices were developed through the blending of modern and traditional methods. As part of these initiatives, both the first manuals on good agricultural practices for amaranth and the first survey of pests and diseases in amaranth were produced. Several technologies were introduced to improve processing, among these new threshing machines suitable for smaller operations and de-saponification machines. New methods of consumption were created with the development of new products and disseminated through preparation and nutrition workshops. The programme developed and disseminated novel and traditional recipes involving Andean grains, including amaranth energy bars and cupcakes in Bolivia, which increased the added value of amaranth while improving child nutrition through school feeding programmes. Several strategies were applied to the marketing of Andean grain products. In one notable intervention, the programme partnered with a privately owned coffee chain that developed, introduced and promoted new Andean grain-based recipes. Surveys of consumer preferences were carried out, and the relevance of alternative uses for Andean grains such as gluten free products was explored.

Finally, steps were taken to educate the public and build farmer capacity. Nutritional and biochemical analyses were carried out, and recommendations on optimal doses of Andean grains in meals for children were developed. Farmers and farmer associations received training in best production practices and nutritional benefits. Overall, more than 1200 households participated in the activities of the programme within its implementation phase.[3]

3 METHODOLOGY

3.1 Source and Methods of Data Collection

The programme impact assessment covered four communities in Bolivia (Santiago de Okola and Coromata Media in the department of La Paz and, Cuevas Cañadas and Mojotorillo communities in Chuquisaca) and four communities in Peru (Cieneguillas and Corisuyo communities in Puno and the communities of Occoruro and Auquiorko in Cuzco). The study involved the use of both primary and secondary data. Collection of primary data was carried out during the first months of 2011 and included focus group discussions, in-depth interviews and a semi-structured questionnaire. In each of the selected villages, the enumerators were required to obtain a list of the households from the village authorities and use it as the sampling frame. The survey tool (semi-structured questionnaire) was pre-tested in Santiago de Okola in Bolivia and Cieneguillas in Peru and adjusted several times before administration, and all research assistants participated.[4]

[3]Overall, more than 60 partners and stakeholders including local NGO and private companies were involved in the programme activities.

[4]The research assistants were trained on sampling and questionnaire administration. They were encouraged to use direct observation and informal interviews to complement the questionnaire. They were encouraged to note extra information and later submitted a written field report alongside the questionnaires. The field report explained in depth some of the issues that were not well captured in the questionnaire, and those issues that were not specific to particular households but whole communities or villages and considered important in the interpretation of data.

Table 1. Sample composition

Country	Region	Community	Participants	Non-participants	Total
Bolivia	La Paz	Santiago de Okola	29	15	44
		Coromata Media	25	16	41
	Chuquisaca	Cuevas Cañadas	31	20	51
		Mojotorillo	20	19	39
Sub-total	—	—	105	70	175
Peru	Puno	Cieneguillas	10	0	10
		Corisuyo	8	0	8
	Cuzco	Auquiorko	11	15	26
		Occoruro	28	13	41
Sub-total	—	—	57	28	85
Total	—	—	162	98	260

A total of 260 randomly selected households were surveyed (175 in Bolivia and 85 in Peru) divided into those that were randomly selected among the participants of the programme (60 per cent in Bolivia and 67 per cent in Peru) and those that were not (40 per cent in Bolivia and 33 per cent in Peru) belonging to eight distinct communities in La Paz and Chuquisaca in Bolivia and Puno and Cuzco in Peru (Table 1).

The research team also held in-depth focus group discussions in each of the survey areas. This was intended to provide qualitative data on some of the crosscutting issues in the communities, including the types of Andean grains varieties known, those that have disappeared, reasons for disappearance, gender issues in production, consumption and marketing, preparation methods and stakeholders involved. In each focus group discussions, gender, age, cultural knowledge and socio-economic classes representation was considered where possible.

3.2 Sample/Participant Description

Table 2 summarises the socio-demographic characteristics of the two groups of households, namely participants and non-participants. Generic information on the household head, general household and farm characteristics were included. The age, education, sex and knowledge of Spanish were measured for the household head. For households, average age and education as well as the number of people in the household, access to indoor water, number of people employed in agriculture and participation rate of the household's members in different organisations were included. Characteristics of the farm, land area, altitude, tractor availability, irrigation and a measure on the overall access to services and facilities were also included.

There were significant differences for participants and non-participants in five variables: household age; whether the household was involved or not in farm organisation; altitude; whether the household had access to services or not, and whether the household had an irrigation system or not. It implies potential sample selection bias. Household participation rate in different organisations, altitude, access to services and facilities and irrigation were all significantly higher for participants, while participating household heads were

Table 2. Sample characteristics of participants and non-participants

Variable	Description	Participants (*obs. 162*)				Non-participants (*obs. 98*)				Dif in Dif[a]
		Mean	Std. dev	Min	Max	Mean	Std. dev	Min	Max	t-test H_0: diff = 0
Household head characteristics										
HH_spanish	1 if HH speak Spanish; 0 otherwise	0.809	—	0	1	0.769	—	0	1	0.040
HH_edu	HH number of years of education	6.015	4.327	0	17	5.487	3.891	0	17	0.528
HH_age	HH age	53.221	15.027	18	85	56.780	15.928	25	91	−3.559*
HH_sex	1 if HH is male; 0 female	0.934	—	0	1	0.897	—	0	1	0.036
Household characteristics										
Size	Number of household members	4.074	2.200	1	10	4.321	2.333	1	10	−0.247
Mean_age	Average age of the household	35.381	18.781	8	82.5	38.060	19.944	11	88	−2.679
Organisation_involvement	Participation rate in different organisations	0.262	0.254	0	0.692	0.105	0.198	0	0.692	0.157***
Indoor_water	1 if access to water; 0 otherwise	0.840	—	0	1	0.796	—	0	1	0.044
Mean_edu	Household average number of years of education	9.037	4.637	0	17	8.397	4.647	0	17	0.639
Agri_labour	Number of employed in agriculture	1.132	0.676	0	4	1.128	0.632	0	3	0.004
Farm characteristics										
Tractor	1 if own a tractor; 0 otherwise	0.056	—	0	1	0.082	—	0	1	−0.026
Area	Land surface (ha)	1.658	1.598	0.01	8	1.492	1.510	0.05	9	0.167
Altitude	Altitude (m)	3227	689	2100	3957	3033	680	2100	3957	193**
Access	Index of access to facilities/services	0.703	0.315	0.071	1.857	0.589	0.279	0	1.429	0.113**
Irrigation	1 if presence of irrigation; 0 otherwise	0.316	—	0	1	0.192	—	0	1	0.124*

[a] t-test H_0: diff = 0.
*$p < 0.10$.
**$p < 0.05$.
***$p < 0.01$.
Two-group Hotelling's T-squared = 49.85; F: 2.75, p-value = 0.0003.

significantly younger by three years. There was no significant difference for the household head's gender, education and knowledge of Spanish; of household size; average age; access to indoor water; education; household members working in agriculture or of farms access to a tractor and land area.

With regards to the participation in the programme, Table 3 summarises participation rates and perceptions of utility for various interventions. For illustrative purposes, all the interventions carried out over the duration of the programme were organised in four areas and nine sub-areas of the value chain process.

Genetic diversity and agronomic and processing practices generally had higher participation rates than marketing, consumption education and capacity building. Harvesting and post-harvesting had the highest participation rate (79.17 per cent) followed by participation in farmers' fairs (76.86 per cent). Utility was rated highly for all interventions with organisational strengthening receiving the highest rating, although this also had the lowest frequency of participation. Table 4 illustrates stated motivations for household participation in interventions: As the table shows, the largest incentives for participating are for free training (57.6 per cent) and improving market knowledge (47.9 per cent). Although genetic diversity programmes had relatively high participation rates, receiving free seed was the least common motivation (22.9 per cent).

3.3 Definition of the Outcome Variables

The first step of the impact assessment involves the design of the outcome measures. These measures have to be case specific and functionally consistent with the programme aim. The selected indicators will refer to the four different areas of intervention of the programme.

Table 3. Programme areas of interventions, participation rate and perceived utility

Programme areas of interventions	Specific interventions	% Participation rate across beneficiaries	Average value of perceived utility[a]
Genetic diversity	Farmers fairs participation	76.86	1.91
	Contests of agrobiodiversity and uses for Andean crops	56.82	1.78
	Introduction and evaluation of new varieties	60.30	2.08
Agronomic and processing practices	Agronomic training	69.20	2.02
	Training for pest control in Andean crops	67.68	2.02
	Harvesting and post-harvesting Andean grains	79.17	2.39
Marketing// Consumption	Development of new product for consumption and selling	51.01	1.93
	Preparation and nutrition workshops on Andean grains	55.56	2.04
Capacity building and knowledge sharing	Organisational strengthening	8.06	1.60

[a]1: very useful–5: not useful.

Table 4. Household motivations for participation (%)

Motivations to participate	Frequency (%)
To receive free training	57.6
To receive free seeds	22.9
To improve market knowledge	47.9
To increase the products sale	34.2

Furthermore, two broad livelihood measures for capturing broader outcomes of households' programme participation have been included (Table 5):

More specifically, as concerns the first area of intervention, *genetic diversity*, two measures were introduced: *native diversity*, indicating the number of native strains of Andean grain, and *introduction diversity*, referring to the number of newly introduced strains. The second area of intervention, *agronomic and processing practices*, is broken down into *production* and *seeding*. *Production* is the quantity produced of Andean grains per year in kg, while *seeding* indicates land area cultivated in Andean grain in Ha, which is a proxy for crop diffusion. *Marketing and consumption* was the next area of intervention and was made up of the two respective subcategories. *Marketing* measures farmers' reported experience with Andean grain marketability through a five-point scale, with five being the greatest ease of marketing. *Consumption* indicates self-reported consumption frequency of Andean grains using a six-item ordinal scale, with one being the lowest consumption and six the highest. *Information exchange* was the only measure in the fourth area of intervention, *capacity building and knowledge sharing*, and is an index of information exchanges on Andean grains, with a number closer to one indicating the greatest flow of information.

Finally, the broad livelihood measures taken were *perceived income* and *perceived food security*. Perceived income is based on self-reported estimated household income expressed in US$. Perceived food security is a self-reported measure from one to three

Table 5. Observed outcomes between participants and non-participants to the programme

	Participants (*obs. 162*)				Non-participants (*obs. 98*)			
Indicators	Mean	Std. dev	Min	Max	Mean	Std. dev	Min	Max
Genetic diversity								
Native diversity	1.43	1.14	0	4	0.79	1.07	0	4
Introduction diversity	1.35	1.06	0	5	0.7	0.94	0	2
Agronomic and processing practice								
Production	329.38	988.04	0	7000	206.08	839.26	0	5000
Seeding	0.48	2.08	0	25	0.31	1.65	0	16
Marketing consumption								
Marketing	0.82	0.85	0	4	0.49	0.77	0	3
Consumption	3.12	1.18	1	6	2.49	1.20	1	6
Capacity building and knowledge sharing								
Information	0.56	NA	0	1	0.27	NA	0	1
Broad livelihood measures								
Perceived income	973.88	773.12	582	7071	815.87	279.82	582	1767
Perceived index of food security	2.26	0.68	1	3	2.09	0.6	1	3

of the food security of the household based on how often there was not enough food available, three indicating there is always enough food and one indicating there is never enough food for the entire family.

3.4 Methods

In general terms, the impact of the programme can be assessed as the variation in an outcome (ΔY) that is attributed to the interventions. Given a set of *I* households that can join the programme and participate in the activities, $Y_{i,1}$ is the observed outcome when the *i*-th households participated (treated) and $Y_{i,0}$ is the outcome if the households did not join the programme (untreated), the programme benefits in terms of causal (treatment) effect results for the generic *i*-th household (Rubin, 1974):

$$\Delta Y_i = \left(Y_{i,1} - Y_{i,0}\right) \tag{1}$$

However ΔY_i cannot be explicitly evaluated, because the *i-th* household cannot be involved in both states (treated and untreated) at the same time. The lack of an appropriate counterfactual cannot be resolved taking the average of outcomes of untreated households in order to estimate the potential outcome of the programme, as the two group outcomes may differ in a systematic manner even in the absence of treatment. Treated (households who participated in the programme) and untreated groups (counterfactual) may show large differences in terms of compounding factors yielding to biased estimates of treatment effects. Therefore, one of the main issues to address in this task is the control for potential sample selection bias.

Among the non-experimental evaluation methods, several econometric models are adopted to evaluate programme outcome: propensity score matching (PSM), regression discontinuity and instrumental variables are some of the available methods in the analytical toolbox (Imbens & Woolridge, 2009; Guo & Fraser, 2010). In the present study, the first strategy for the causal analysis was followed: in order to reduce the multidimensional compounding factors that may influence the participation in only one score, it is worth using PSM. PSM has been largely used in disciplines such as, medicine, education and social sciences including development studies for assessing programme impacts (Dehejia & Wahba, 1999; Abebaw, Yibeltal, & Belay, 2010; Wanjala & Muradian, 2013)[5].Let X_i be a vector of pre-intervention characteristics for the *i-th* household (i = 1,…, I), and $p(X_i)$ the conditional probability of being treated or *propensity score* (W_i = 1) versus untreated (W_i = 0):

$$p(X_i) = pr[W_i = 1|X_i] \tag{2}$$

$p(X_i)$ can be expressed as $F[H(X_i)]$. Functional forms of F most frequently used are the normal or logistic probability density function. This study estimates the propensity scores $p(X_i)$ by a logit model with the dependent variable coded as 1 for treated households and 0

[5]Since the seminal work of Rosenbaum and Rubin (1983) on propensity score analysis, this method is becoming more and more popular in observational studies, taking correctly into account the above described source of correlation. When participation in a programme, or in a peculiar social setting, is not randomly assigned but it is stochastically depending on a number of variables observables in observational studies, PSM can be implemented as a measure of conditional probability of treatment participation conditional to the observed variables (covariates). PSM allows in fact to compare to each households the outcome associated with that non-participant most closely in terms of observable characteristics.

for untreated households. Rosenbaum and Rubin (1983) demonstrate that given the propensity score $p(X_i)$, observed covariates become conditionally independent with the programme participation:

$$X_i \perp W_i | \, p(X_i) \tag{3}$$

Moreover, the mean difference of the outcome variable between participants and non-participants for all households with the same value of the propensity score is an unbiased estimate of the average treatment effect (ATE) at that propensity score. That is,

$$\begin{aligned} \mathrm{ATE} &= \mathrm{E}\left[\mathrm{E}\left(\mathrm{Y_{i,1}}, |p(\mathrm{X_i}), \mathrm{W_i} = 1\right) - \mathrm{E}(\mathrm{Y_{i0}}, |p(\mathrm{X_i}), \mathrm{W_i} = 0)\right] \\ &= \mathrm{E}\left[\mathrm{Y_{i,1}} - \mathrm{Y_{i,0}}| \, p(\mathrm{X_i})\right]. \end{aligned} \tag{4}$$

This property links the propensity score model to equation 1, and shows how the problem of not observing the same households in both states (treated and untreated) can be analytically resolved.

More in detail, the ATE on the treated (ATET) will be computed in this study:

$$\mathrm{ATET} = E[\Delta Y_i \mid p(X_i), W_i = 1] \tag{5}$$

Moreover, in addition to the simple analysis of the ATET, a doubly robust estimator is implemented, giving the opportunity for controlling different forms of model misspecification due confounding effects and selection bias (Emsley, Lunt, Pickles, & Dunn, 2008; Wanjala & Muradian, 2013):

$$DR = \frac{1}{N}\sum_{i=1}^{N} \frac{W_i Y_i - \left(W_i - \widehat{p(X_i)}\right)\hat{Y}_{i1}}{\widehat{p(X_i)}} - \frac{1}{N}\sum_{i=1}^{N} \frac{(1 - W_i)Y_i + \left(W_i - \widehat{p(X_i)}\right)\hat{Y}_{i0}}{1 - \widehat{p(X_i)}}. \tag{6}$$

4 RESULTS

4.1 Propensity Score Estimates

A logit model was used to estimate the propensity score: only variables statistically significant by at least 10 per cent were kept in the model to ensure the best fit. The final propensity score was based on a model including household head age, access to facilities/services, whether the household was from Cuzco, altitude and involvement in organisations (Table 6). The variables closely match up to those previously identified as significantly different using *t*-tests, though with the Cuzco variable and without the irrigation variable.

Figure 3 graphically illustrates propensity scores for the treated and untreated groups. From the propensity score estimation, we obtain groups with different numbers of treated and untreated units, making sure that each group benefits of the balancing property.[6] It is done by using, within each group, only those observations that show a propensity score laying in the intersection of the supports of the propensity score of the treated and the non-treated units between 0.274 and 0.989.The range of propensity scores for each group was:

[6]Balancing property was satisfied following Becker and Ichino (2002) strategy. Both the average propensity score and the average for each explanatory variable between treated and untreated have to be equal.

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Table 6. Propensity score estimates (logit regression)

Variable	Coef.	Std. dev	*t*-stat	*p*-value
HH_age	−0.025	0.010	−2.42	0.015
Access	1.220	0.597	2.04	0.041
Cuzco	−1.499	0.418	−3.58	0
Altitude	0.001	0.000	2.19	0.029
Organisation_involvment	3.515	0.752	4.67	0
Constant	−0.664	0.742	−0.89	0.371

#obs 260 Pseudo R^2 0.145; Lr $\chi(5) = 50.1$; *loglikelihood* = −147.23.

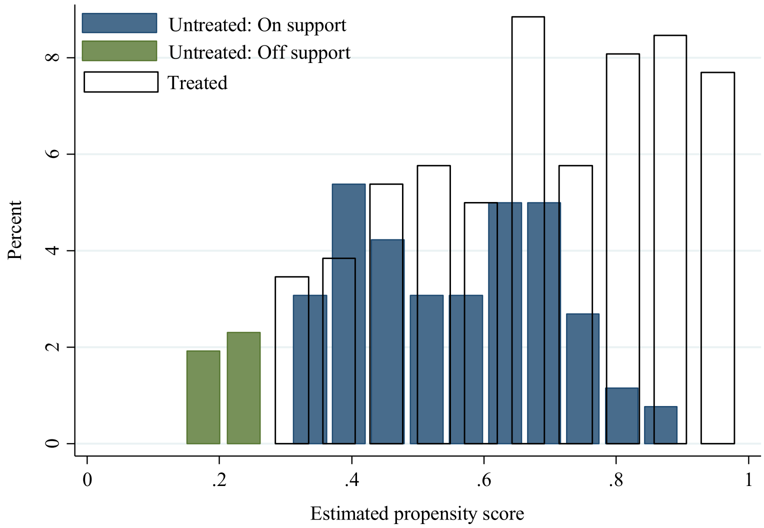

Figure 3. Graph of propensity scores [Colour figure can be viewed at wileyonlinelibrary.com]

Untreated : $0.308 \le pscore \le 0.897$
Treated : $0.274 \le pscore \le 0.989$

As a result, only a portion of the original sample is taken into account. The area of common support (similar propensity scores) between treated and untreated groups is very high (96 per cent), and the balancing property was satisfied at significance level of $p < 0.10$. Matching resulted in a significant reduction in mean bias; with an *F* statistics of the Hotelling's *T*-squared generalised means within participants and non-participants drop from *F*: 2.75 (*p*-value <0.01) (biased comparison of the sample mean) to 0.870 (*p*-value = 0.61) (with propensity score reweighting).

4.2 ATET Estimation

In order to ensure the robustness of ATET estimation, we implemented some of the methods suggested by Smith and Todd (2005): nearest neighbour-matching and kernel-matching. Becker and Ichino (2002) discuss in detail the algorithms used and the pros and cons of each method. Because no scientific evidence exists to support which alternative is superior to other methods, both the results are reported. However, the different methods are consistent with each other, confirming direction, significance and magnitude of the estimated ATETs. In order to verify which outcome showed a significant difference between participant and non-participant households, a *t*-test was performed and reported in the tables. Moreover, the robustness of the results against the presence of unobserved heterogeneity (*hidden bias*) between treated and untreated households was tested by using the Rosenbaum sensitivity bounds strategy[7] (Rosenbaum, 2002) (Table 7).

Both genetic diversity outcomes were significantly higher in the treatment group than the untreated group indicating programme success in promoting *in situ* conservation. Native diversity increased by 74 to 79.5 per cent depending on the model, while introduced diversity increased by 81 to 87.9 per cent, indicating treated farms had on average almost one more variety of each type compared to untreated farms. This provides evidence for the efficacy of *in situ* conservation within the communities participating in the programme. Within agronomic and processing practices, the ATET estimation was negative but non-significant in both models. Marketing and consumption were higher in the treated group, but the result was only significant under the kernel-matching model (and not robust against *hidden-bias* at least for marketing), giving inconclusive evidence of programme effects in this area. Information was significantly positive under both models, indicating the programme appears to lead to greater participation in information sharing from treated farmers. There were differing results for broad livelihood measures; perceived income had a significant increase of around $162 while perceived food security had a non-significant negative ATET. Because there is no evidence of production gains, this increase in income likely comes from increase in value because of genetic diversity, and/or new ways of marketing and consumption. One of the possible explanations for this outcome may be that participants were more ready to exploit the opportunities given by the increased importance of quinoa in both national and international markets. The lack of an effect on food security could indicate these benefits on income are not as great for the most food-insecure households.

4.3 Doubly Robust Estimators

Doubly robust estimates of treatment on the outcomes of interest were calculated for controlling potential confounding factors on the outcome (Table 8).

Income was still significant but only increased by $113, while results for food security were still non-significant. Information was significantly higher with treatment increasing the index score, which ranged from 0 to 1 by 0.29. The ambiguity with regards to marketing and consumption disappeared in this model. Marketing was no longer significantly different from untreated households but consumption significantly increased pointing towards an increase in self-consumption of Andean grain. Native and introduced diversity saw significant positive results. Neither measure of agronomic practices, seeding nor production was significantly changed, confirming the previous results.

[7]Table 7 includes Wilcoxon signed rank tests (*p*-critical), indicating the lowest ($p-$) or the highest ($p+$) bound on the significance level of the ATET reflecting assumption about endogeneity in treatment assignment in terms of the odds ratio of differential treatment assignment due to unobserved covariates or Γ. *p*-critical values are reported with Γ equal to 2.

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Table 7. Estimates of ATET with nearest neighbour-matching and kernel-matching

—	Nearest neighbour-matching				Kernel-matching			
	ATET	*p*-value[a]	*p*-critical[b]	% Benchmark	ATET	*p*-value[c]	*p*-critical[b]	%Benchmark
Genetic diversity								
Native diversity	0.605	0.029	0.062	74.1	0.648	0.001	0.001	79.5
Introduction diversity	0.586	0.026	0.049	81.0	0.637	0.001	0.001	87.9
Agronomic and processing practice								
Production	−305.3	0.883	0.976	−40.9	−48.4	0.837	0.397	−20.9
Seeding	−0.143	0.477	0.996	−132.0	−0.188	0.745	0.853	−53.8
Marketing consumption								
Marketing	0.228	0.285	0.764	44.2	0.292	0.043	0.830	56.4
Consumption	0.621	0.170	0.547	24.5	0.776	0.005	0.002	30.7
Capacity building and knowledge sharing								
Information	0.274	0.007	0.002	108.4	0.299	0.000	0.000	118.1
Broad livelihood measures								
Perceived income	161.9	0.092	0.068	20.3	161.0	0.028	0.051	20.2
Perceived index of food security	−0.028	0.863	1.000	−1.3	0.018	0.876	1.000	0.9

[a]Calculated on bootstrapped standard errors with 400 replications.
[b]'*p*-critical' is p^- (lowest bound of significance) for Native diversity, Introduction diversity, Marketing, Consumption, Information and Perceived income, while is p^+ (highest bound of significance) for Production, Seeding and Perceived index of food security.

Table 8. Estimation using the doubly robust estimator

Area of interventions	ATET	Std. dev
Genetic diversity		
Native diversity	0.37**	0.17
Introduced diversity	0.39***	0.15
Agronomic and processing practice		
Production	−56.55	180.25
Seeding	−0.32	0.43
Marketing consumption		
Marketing	0.04	0.12
Consumption	0.48**	0.2
Capacity building and knowledge sharing		
Information	0.29***	0.05
Broad livelihood measures		
Perceived income	113.26**	50.58
Food security	0.11	0.11

*$p < 0.10$.
**$p < 0.05$.
***$p < 0.01$.

4.4 Analysis on the Heterogeneity of Effects

Following Wanjala and Muradian (2013) and Abebaw *et al.* (2010), in order to deepen the understanding of the heterogeneity of the programme effect among households, a set of regressions was applied. In detail, for each outcome significantly affected by the programme, a regression equation was set up, where the individual household treatment effects (TETi) were regressed against the household and farm characteristics (Table 9).

Whether the household head spoke Spanish had significant effects in all the regressions. It had a negative effect on both diversity measures, perhaps suggesting higher crop variation is found in households with looser links to the wider Spanish-speaking societies, while the Spanish speakers show a stronger market orientation. Thus, Spanish had positive effects on consumption of Andean grains, information-sharing and perceived income. Household head sex only had a significant effect on native diversity, with males having greater diversity, probably due a greater availability of workforce. Greater organisational involvement significantly increased consumption of Andean grains, suggesting these were useful places to spread knowledge of the benefits of Andean grains, as well improving perceived income. Land area and altitude both had positive effects on both types of diversity while only land area had positive effects on Andean grain consumption and only altitude had negative effects on information sharing, possibly because of terrain. Finally, consumption of Andean grains was also positively affected by access to facilities and irrigation.

5 DISCUSSIONS AND CONCLUSIONS

One of the major challenges faced by donors, policy makers and practitioners that consider it important to fund, design and implement projects that address issues of the sustainable use of crop diversity in the context of rural livelihoods is to identify the likely intervention pathways needed in order to reach impact. This paper using a theory-based approach

Table 9. Determinants estimates of household treatment effects

—	Native diversity	Introduction diversity	Consumption	Information	Perceived income
Household head characteristics					
HH_spanish	−0.893 ***	−0.918 ***	0.818 ***	0.144 *	497.659 **
HH_edu	−0.036	−0.008	0.027	0.017 *	15.314
HH_age	0.014	−0.001	0.019	0.001	−5.489
HH_sex	0.712 *	0.416	−0.183	−0.182	22.014
Household characteristics					
Size	−0.091	−0.018	−0.016	0.024	−40.144
Mean_age	−0.002	0.016	−0.022	0.003	1.675
Organisation_involvment	−0.153	0.045	1.351 ***	0.070	588.137 **
Indoor_water	0.049	−0.145	−0.024	0.090	131.549
Mean_edu	0.035	0.037	−0.042	0.001	4.330
Agri_labour	0.055	0.057	0.060	−0.011	−116.490
Farm characteristics					
Tractor	−0.332	−0.428	−0.253	−0.020	−165.273
Area	0.108 *	0.155 ***	0.140 **	0.027	54.291
Altitude	0.001 ***	0.001 ***	0.001	−0.001 ***	−0.092
Access	−0.295	−0.218	1.175 ***	0.131	679.227 ***
Irrigation	−0.042	0.007	0.330 *	0.006	−113.017
_cons	−1.290 *	−1.329 **	−1.746***	0.354 *	−350.908
Adj R-squared	0.098	0.1005	0.3089	0.1909	0.2136
Prob > F	0.010	0.0087	0.000	0	0

*$p < 0.10$.
**$p < 0.05$.
***$p < 0.01$.

(Bellon *et al.,* 2015a) assesses the sustainable impact at household level of a research-for-development programme based on holistic approaches, which pursue inter-disciplinary collaboration in Bolivia and Peru. Participants were trained in various activities, including the introduction of new varieties, plant protection, better agronomic and processing practices, development of new modes of consumption, value creation and the exchange and sharing of new knowledge. Furthermore, stakeholder awareness of the opportunities related to Andean grains was raised through workshops on Andean grains and farmers' fairs.

A quantitative assessment of the programme impact was performed, confronting outcomes of households participating in the programme activities with a counterfactual given by a control group drawn from households that did not participate. Results show that the research-for-development programme in Bolivia and in Peru had an impact in terms of crop diversity, income generation and on improving people's well-being. These changes could be a result of increased home consumption and marketing opportunities generated by an active participation in the programme. When analysed in detail, it was observed that the participation in the programme positively influenced the exchange of information on Andean crops among participants, whilst facilitating the conservation of native diversity and the introduction of new varieties. Consumption of Andean crops was higher among the participants as opposed to non-participants, while propensity of marketing was higher, but not statistically significant against hidden bias. Results from a doubly robust model confirm all the estimates given by PSM, supporting, moreover, the hypothesis that programme participation lacks a statistical impact on marketing-related outcomes.

In terms of outcomes related to livelihood measures, the participation in the programme had a positive impact on the perceived income of the participants. As concerns this latter point, a rough cost–benefit analysis could be drawn, calculating and comparing private benefits and public costs of the implemented programme. Quantitative estimates show that the interventions contributed by generating additional annual revenue of US$113 on average for each participating household in the programme sites. These estimated values concern a sample of 160 households surveyed during the ex-post assessment. However, as inferential techniques were used in the analysis, it is possible to make a rough inference about the total population from the sample. Overall, 1200 households were involved in the implementation of the programme. A precautionary estimate would indicate that overall, these households benefitted from at least US$63 per year as additional income gained (average value minus one standard deviation), a total of around US$75 000 per year. The value does not take into account any spillover effects that might increase the number of beneficiaries. The value constitutes the payoff of intervention: with the assumption that the income gain would persist at least over six years, it could match the total cost of the programme in both countries (approximately US$460 000). If this calculation also accounted for other private benefits (i.e. increased consumption of quality nutritious foods) or the wide range of public benefits (i.e. related to ecosystem services), the payoff would be much higher. These figures must however be treated with caution, as the income index used (based on a categorical scale) was relatively superficial.

These results also seem to confirm the findings of Gotor *et al.* (2013) and Isakson (2011), presenting the effectiveness of programmes aimed at improving rural livelihoods through greater knowledge transfer and use of local agrobiodiversity: private benefits associated to the programme interventions could incentivise households to consider the use and preservation of the agrobiodiversity beyond the lifetime of the programme. It could thus ensure a sustainable process in which optimisation of private benefits is coupled with the provision of public benefits.

Key limitations of this study lie primarily in the generalisability of the results. Many research and development programs have focused on the preservation of agrobiodiversity, as well as of traditional knowledge, as a way to empower and to improve the well-being of rural communities (Wale, 2008) in a sustainable, long-term manner. However, despite the short-term outcomes in areas such as genetic diversity conservation, yields and agronomic management that are well documented (Gotor *et al.,* 2013), there is still a lack of structured and analytic assessment of the success of these projects in terms of broader and longer term gains, beyond immediate training (Lutz & Munasingheb, 1994). Economic benefits of conserving and safeguarding agricultural biodiversity (as public goods) tend to be limited in the short term but significant in the long one. However, costs, in terms of foregone development opportunities, tend to be significant in the short term and moderate in the long one. Tracing impact and its suitability over time present particular problems that require rethinking or adapting existing methodologies or creating new ways of approaching the assessment of impact across temporal scales (White, 2010). This study should be seen as a first attempt to fill this gap. Moreover the rigour of the adopted empirical strategy contributed to the discussion of the usefulness and validity of quasi-experimental approaches in this field, where randomised control trials are not recommended, given, the reliance of the interventions on the interest, motivation and capacity of the households (Barrett & Carter, 2010).

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