The Southern Altiplano of Bolivia

Thierry Winkel, Ricardo Alvarez-Flores, Pierre Bommel, Jean Bourliaud, Marco Chevarria Lazo, Geneviève Cortes, Pablo Cruz, C. del Castillo, Pierre Gasselin, Richard Joffre, et al.

CHAPTER: 5.1.b

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Author for correspondence: Thierry WINKEL *thierry.winkel@ird.fr*

Authors:

Winkel T.[a]; Álvarez-Flores R.[b]; Bommel P.[c]; Bourliaud J.[d]; Chevarría Lazo M.[e]; Cortes G.[f]; Cruz P.[g]; Del Castillo C.[h]; Gasselin P.[i]; Joffre R.[j]; Léger F.[k]; Nina Laura J.p.[l]; Rambal S.[j]; Rivière G.[m]; Tichit M.[i]; Tourrand J.f.[c]; Vassas Toral A.[n]; Vieira Pak M[c].

[a] IRD, UMR 5175 CEFE, Montpellier, France - [b] CNRS, UMR 5175 CEFE, Montpellier, France
[c] CIRAD, UR GREEN, Montpellier, France - [d] INRA, UR MONA, Ivry-sur-Seine, France
[e] Consultor ONU (UNOPS - PNUMA), Peru
[f] Université Paul Valéry, UMR 5281 ART-Dev, Montpellier, France
[g] CONICET-FUNDANDES, Jujuy, Argentina - [h] UMSA, Facultad de Agronomía, La Paz, Bolivia
[i] INRA, UMR INNOVATION, Montpellier, France - [j] CNRS, UMR 5175 CEFE, Montpellier, France
[k] INRA, UMR SAD-APT, Paris, France - [l] Agrónomos y Veterinarios Sin Fronteras, La Paz, Bolivia
[m] EHESS, UMR 8168 MASCIPO, Paris, France
[n] Université Paul Valéry, UMR 5281 ART-Dev, Montpellier, France

Abstract

Quinoa has been a staple food for Andean populations for millennia. Today, it is a much-appreciated product on the international health-food, organic and fair-trade food markets. Quinoa producers in the southern Altiplano of Bolivia initiated this change approximately 40 years ago. On high desert land, they succeeded in developing a thriving agricultural crop for export. Although they enjoy lucrative niche markets, quinoa producers are not specialized farmers, nor do most of them live year-round in the production area. These are some of the paradoxes that characterize quinoa production in the southern Altiplano of Bolivia. Following a description of the origin, diversity and biological traits of the 'Quinoa Real' ecotype, on which production in this area is based, this chapter explores the importance of quinoa in local agrosystems and in the systems of agricultural and non-agricultural activities managed by southern Altiplano families. Geographic mobility and pluriactivity are part of the ancestral lifestyle of these populations and have to date determined how territorial resources are used and producers are organized in the context of quinoa's commercial success. Quinoa production in the region is presenting signs of agro-ecological and social vulnerability; however, it has the capacities to respond and adapt accordingly. Key points for the sustainability of local agrosystems are: i) harmonization of communal and individual regulations concerning access to and use of land in socially equitable agrosystems with a balance between crops and animal husbandry, ii) international standards for the recognition of 'Quinoa Real' in export markets, iii) continuous updating of rules and regulations so that local agrosystems can adapt to unpredictable changes in the socio-ecological context on different scales of space and time.

Key words: social adaptability, family farming, Bolivia, ecotype, territorial rules and regulations, pluriactivity, 'Quinoa Real', socio-ecological system, agricultural sustainability.

Context and issues of quinoa in the southern Altiplano of Bolivia

World leadership: the result of 40 years of efforts

The southern Altiplano of Bolivia dominates the international quinoa industry, with production – depending on the year – accounting for up to 90% of world exports (Aroni *et al.*, 2009; Rojas, 2011). In the 1970s in the area of Lípez, on the southern edge of the Uyuni salt flats, quinoa production for export began to rapidly spread, and continued to do so in the 1980s, towards the west and north of the salt flats, a region known as the Intersalar (Figure 1). Production on a large scale was initially a response to the commercial demand from neighbouring Peru, which had a larger population with a significant proportion of city-dwellers ate large amounts of quinoa (unlike the situation in Bolivia at the time). A Belgian non-governmental organization (NGO) working in communities in the area donated tractors to boost the initial phase of production (Laguna, 2011). Southern Altiplano farmers were thus able to respond in a timely manner to rising commercial demand from North America and Europe for vegetarian, gluten-free and protein-rich foods in the 1980s. Markets soon opened up for fair-trade and organic products, sustained mainly by European demand. The new export markets in the Northern Hemisphere did not supplant the Peruvian market, which until recently accounted for over half of quinoa exports from Bolivia (albeit mainly in the informal economy) (Aroni *et al.*, 2009). Today, local quinoa farmers make the most of a variety of markets, offering conventional quinoa, certified organic quinoa and certified fair-trade quinoa for the domestic market, the Peruvian informal sector and markets in the Northern Hemisphere.

Four paradoxes of quinoa production in the southern Altiplano

The growing international demand for quinoa places producers and their organizations in a privileged position for negotiating with importers, usually foreigners. Despite their success in export markets, however, local producers have not chosen to become definitively specialized in quinoa farming. On the contrary, the majority of them simultaneously continue non-agricultural activities, often involving temporary migration (Vassas Toral, 2011). Cultiva-

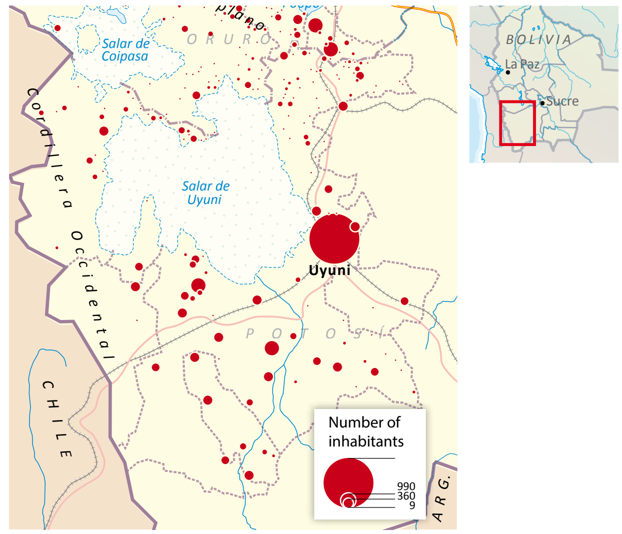

Figure 1: Map of communities in the southern Altiplano of Bolivia

tion of export crops by farmers not permanently resident in the rural area is just one of the paradoxes of quinoa farming in the southern Altiplano of Bolivia (Winkel, 2011).

The environment is characterized by extreme conditions – rocky or sandy soil almost permanently exposed to drought, frost, El Niño events, violent winds and intense solar radiation due to the high altitude – and it is surprising that an export crop has managed to flourish so successfully. To our knowledge, quinoa is a unique case worldwide: an export crop, produced practically without inputs, in an extreme environment of cold, arid high mountains. Growing areas, located at elevations of between 3 650 and 4 200 m asl, receive annual precipitation ranging from 150 mm in the south of the region to 300 mm in the northeast, with more than 200 days of frost a year (Geerts *et al.*, 2006). Quinoa has high tolerance to drought, but it is nevertheless unable to complete its vegetative cycle with only the rainfall received in an average year. For this reason, a 2-year fallow land system is adopted: the first year, precipitation accumulates in the soil; the second year, there is a full 1-year growing cycle (Michel, 2008).

Another paradox of quinoa production in this region is that, while being a healthy food grown by small producers, sometimes with organic and/or fair-trade certification, its cultivation could jeopardize the ecological and social foundations of the agrosystem (Michel, 2008; Vieira Pak, 2012). This situation goes against the desired benefits of family farming, which uses low levels of inputs and advocates ancestral roots and knowledge. Concerns about the sustainability of quinoa production were initially expressed, often in simplistic and alarmist terms, by journalists, businesspeople and researchers, who reported increasing soil erosion and highlighted the short-term vision and profit motives of some local producers and operators. Farmers and decision-makers in Bolivia are aware of the growing environmental and social vulnerability of their agroecosystem; therefore,, with the support of national and international institutions, they have begun to take initiatives to resolve emerging problems.

This leads us to another paradox of quinoa production, this time socio-economic. For three decades, the quinoa boom was essentially the result of sectorial and individual initiatives developed in an "organizational vacuum" (Félix and Vilca, 2009). In contrast, during the last 10 years, there has been an attempt to establish collective regulations at local, national and international level, involving community authorities, producers' associations, NGOs, rural development agencies, regional and central governments, and international food chains. While there are numerous cases worldwide of rural populations denied access to their own territorial resources, the southern Altiplano of Bolivia, in contrast, is an example of rural populations controlling the access to local land and seed resources, in addition to most export markets. By taking advantage of the growing global demand for grains, they are able to resist regulatory pressures from the outside.

This brief assessment of quinoa production in the southern Altiplano of Bolivia, will now examine the dynamics of the export market. The quinoa boom, beginning at the end of the 1970s, has yet to show signs of slowing down. Indeed, between 2000 and 2010, the value of exports increased fortyfold, totalling more than USD45 million. During the same period, average prices to the producer rose from USD1 200 to more than USD3 000 per tonne of standard quality quinoa (Rojas, 2011). These exceptional productive and commercial dynamics challenge the ecological, social and economic foundations of a sustainable agrosystem and present all the characteristics of a genuine agricultural revolution (Mazoyer and Roudart, 2006, 2009). While individual improvisation was initially the rule, initiatives are now emerging to renew the collective practices of local resource management.

The diversity, origins and uses of genetic resources

Dozens of local varieties, a single ecotype?

The southern Altiplano of Bolivia is the land of 'Quinoa Real'. Contrary to common belief, 'Quinoa Real' is not one variety of quinoa: nearly 50 local varieties fall under the generic name of 'Quinoa Real', each one identified by its common name and phenotype (Bonifacio *et al.*, 2012). These local varieties can be differentiated by the form of their panicles: amarantiform, glomerular or intermediate. Their leaves, panicles and grains also present very diverse and sometimes mixed colours, from green to yellow and purple for the leaves, and from white to pink, red, orange, yellow, violet, coffee and black for the panicles and the whole grains. The pigmentation in the grains is, however, generally unstable. Once the quinoa has been washed and the saponin removed, the grains of most 'Quinoa Real' varieties take on a white or cream colour. The grains of only a few varieties remain dark red, brown or black. Today, there is commercial demand for both types of grains: white and dark. The rarer coloured grains fetch a much higher price on the market: USD4 500/tonne against USD2 600/tonne for white grain quinoa (values as at May 2013, source: InfoQuinua.bo). The affirmation that the recent expansion of 'Quinoa Real' production has been detrimental to the diversity of quinoa cultivated in the region prior to the export boom is therefore erroneous.

Another common and unproven theory is that the local varieties of 'Quinoa Real' are distinct ecotypes, each one adapted to a specific microhabitat. If an ecotype is defined as a genotype within a species, that is different because of traits resulting from the selective action of local environmental factors (Zeven, 1998; Soraide Lozano, 2011; Bonifacio et *al.*, 2012), there is currently no evidence that the distinct varieties of 'Quinoa Real' can be differentiated by means of this ecological criterion. Indeed, during the recent period of expansion, the same varieties have occupied mountainsides and plains, regardless of the microclimate, topography or soil type of these different habitats. The capacity of each variety of 'Quinoa Real' to grow in ecologically diverse environments within the region is an essential adaptive feature in a very unpredictable mountainous environment, where specialization limited to a specific habitat or microclimate would be extremely risky and counterproductive. Such a wide adaptive capacity has been called "ecological versatility" by Zimmerer (1998), who, in a study of potatoes in the Peruvian Andes, demonstrated the preservation of agrobiodiversity and sustainable production in agrosystems using few artificial inputs. This ecological versatility does not mean that the notion of ecotype has no relevance in quinoa; rather, the ecotype is defined on a much larger scale than that of local variety and microhabitat. Accordingly, all the local varieties of 'Quinoa Real' which are very productive in the Bolivian southern Altiplano are vulnerable to mildew when planted in the Lake Titicaca area where the air is more humid and temperate than in their home region (Danielsen *et al.*, 2003). On the other hand, northern Altiplano varieties can barely withstand the cold drought conditions around the Uyuni salt flats. Further detailed studies are required to determine the optimum growing areas for the many local varieties of quinoa. In particular, ecophysiological analyses need to be conducted to understand how varieties adapt to different soil types, since this may constitute a factor of ecological differentiation within the large agroclimatic zone of the southern Altiplano. Recent studies comparing 'Quinoa Real' (Salare ecotype) and the Chilean Coastal ecotype reveal distinct capacities for exploring and exploiting the soil (Álvarez-Flores, 2012; Álvarez-Flores *et al.*, 2014; see Chapter 2.8). Until more precise data are available, however, the quinoa ecotypes must be regarded as corresponding to the large agroclimatic regions of their area of distribution: central Altiplano, arid Altiplano, dry valleys, humid valleys and the coast. This wide ecotypic differentiation – without a specific microhabitat – matches the main genetic types of quinoa identified in the pioneering work by Wilson (1988) and largely corroborated with respect to Bolivia by Rojas (2003), Bertero *et al.* (2004) and Del Castillo *et al.* (2006). In this regard, the 'Quinoa Real' varieties correspond as a group to the "arid Altiplano" quinoa (Salare ecotype).

Ancient, and as yet unaltered, genetic resources

With regard to the origins of quinoa in the southern Altiplano of Bolivia, a comparative study based on molecular markers in the genome of ancient quinoa grains found in archaeological sites and of modern grains collected in the region, has revealed an almost perfect match between genotypes during a period of more than 650 years (Grasset, 2011, Programa ECOS-Sud Arqueoquinoas, unpublished data). This similarity suggests a pre-Incan origin for the local varieties still cultivated today in the area of the Uyuni salt flats. It also shows the absence of genetic erosion in quinoa germplasm, despite the many social and environmental changes in the region through time: the pre-Incan era, the Inca and Spanish conquests, the Little Ice Age, the colonial and republican periods, and the current expansion of export crops.

The absence of any appreciable impact on the genetic diversity of quinoa during the recent boom, as pointed out by Del Castillo *et al.* (2007), has at least two explanations. First, different kinds of quinoa have continued to be used locally for a wide range of food preparations (see the section below on food uses in the area), as well as for medicinal and ritual uses. Second, the commercial product, 'Quinoa Real', is identified with a set of diverse varieties which were traditionally cultivated and which have now found a market: white grain quinoa, dark grain quinoa and quinoa for puffed grains (*pipocas*). White grain quinoa has the greatest share of sales and it is also the quinoa with the largest number of local varieties: 44, according to the catalogue published by Bonifacio *et al.* (2012). Dark grain varieties and those used for puffed quinoa are marginal commercial products that nevertheless allow very special varieties to be maintained within the 'Quinoa Real' group. There are seven varieties of dark grain quinoas, two of which – *phisanqalla amarantiforme* and *phisanqalla hembra* – are suitable for puffed quinoa.

This diversity of genetic resources satisfies producers, buyers and consumers of 'Quinoa Real'. Despite the efforts of research laboratories and public institutions, improved varieties and certified seeds have not created much interest among farmers (Baudoin-Farah, 2009). When counterproductive goals are not being pursued – for example, the removal of bitterness from the grains of some varieties ("counterproductive", because the bitterness was actually an effective protection against birds and other animal pests) – genetic improvement research sometimes runs into genuine biological obstacles. For example, resistance to mildew has been linked to agronomic characteristics, such as small grain size and a long vegetative cycle, which are unsuitable for a commercial crop (Gamarra *et al.*, 2001). In managing genetic 'Quinoa Real' resources, there is a fine line between genetic improvement and participatory plant breeding, between uniformization of seeds and preservation of agrobiodiversity, between private interests and collective heritage.

From production certification to designation of origin

Rather than pursuing seed certification, quinoa growers are interested in certifying grain production. Whether organic or fair trade, certification of 'Quinoa Real' is an established process, encouraged since the beginning of the 1990s by the National Association of Quinoa Producers (ANAPQUI) with the support of European NGOs (Laguna, 2011). According to local estimates, 25–40% of today's 'Quinoa Real' production in the region is marketed as "organic". Exports to Europe and North America comprise almost exclusively this type of quinoa (MDRyT and CONACOPROQ, 2009; Aroni *et al.*, 2009).

With regard to the use of genetic resources, the Government of Bolivia, faced with growing competition in international markets, issued a general policy document indicating that "an indispensable and pending task [is] to obtain the quinoa designation of origin [*Denominación de Origen*], for legal and commercial purposes" (MDRyT and CONACOPROQ, 2009). In Bolivia, the "Quinoa Real" designation of origin was approved in 2002 by the National Intellectual Property Service (SENAPI), and a technical document was published in 2011 to promote the distinctness of the product and to protect its geographic and cultural origins (Soraide Lozano, 2011). Similarly, farmers in the area of Lípez (to the south of the Uyuni salt flats) began a designation of origin process in 2009 for their own local crops (Laguna, 2011; Ofstehage, 2012). Nonetheless, on the international scene, the lack of consistency in the many rules and regulations regarding the legal management of plant genetic resources hinders the sovereignty of states and the rights of farmers over these resources (Chevarría-Lazo and Bourliaud, 2011).

Importance of quinoa in the agrosystem and systems of family activities

An agricultural landscape in profound transformation

The majority of the crops that make up the richness of Andean agriculture – Andean tubers and grains, broad beans, green vegetables, forage plants etc. – can only be grown in areas with sufficient access to water. In most of the cold and arid southern Altiplano, the options are restricted to growing potatoes (sweet and bitter) and quinoa. Even before the recent success of export crops, and despite the very harsh environmental conditions, growing potatoes and quinoa was generally sufficient not only for families' personal consumption, but also for supplying local markets and, in particular, mining camps (Franqueville, 2000; Laguna, 2011).

Traditionally, agricultural plots were located on mountainsides: they are less exposed to night-time frost than the plains, while the plains were mainly used for grazing llamas and sheep, which can withstand the cold better than crops (Pouteau *et al.*, 2011). To this day, the pasturelands are owned and used collectively, while the farming plots, although belonging to the communities, are used individually and are generally passed down within the family (Félix and Vilca, 2009; Vieira Pak, 2012). As international demand for quinoa emerged in the 1970s, cultivation extended into the plains and tractors were used to increase production. It should be noted that in this region, on both mountainsides and plains, quinoa is grown on non-irrigated lands, sown in holes – not in furrows as in the rest of the Bolivian Altiplano.

Given the subsidies for rice and wheat consumption granted by international food aid programmes since the 1960s (Franqueville, 2000), and considering the lack of major livestock markets, local producers decided to limit potato crops to family consumption and to convert an increasing share of pastureland for quinoa crops. Figure 2 shows how quinoa crops expanded in a community near the Uyuni salt flats. Between 1963 and 2006, the cultivated area grew by 360%, spreading mainly to the plains, although the mountainsides were still cultivated. An independent study conducted in three towns in this area shows that between 1975 and 2010 the cultivation of quinoa increased by 70–300% on flat land and

Figure 2: Expansion of cultivated areas between 1963 and 2006 in a community in the southern Altiplano of Bolivia. Source: Jean-Rémi Duprat. CNRS – UMR 5175, EQUECO Project, 2008.

decreased by 16–32% on mountainsides (Medrano Echalar *et al.*, 2011). This expansion has led to the uniformization of the agricultural landscape. There are vast monocultures of quinoa and fallow plots while the native vegetation – grasses and bushes that make up the *tola* – is increasingly relegated to marginal, rocky land or mountainsides that cannot be worked by machines (Michel, 2008).

Quinoa in the family system of activities

These changes to the local agrosystem have occurred in a socio-economic context in which agriculture and animal husbandry are part of a system comprising a range of agricultural and non-agricultural family activities. In an arid region that for a long time had a marginal role in the national economy, pluriactivity and temporary migration have been part of families' strategies to adjust to environmental and economic risks (Saignes, 1995; Vassas Toral, 2011). Making the most of their proximity to contrasting ecoregions, such as the Pacific coast to the west and the Inter-Andean valleys and tropical grasslands to the east, the inhabitants of the southern Altiplano have over the centuries developed a way of life based on trading natural resources between these distinct regions (Platt, 1995; Flores Ovando, 2008). Wool, llama leather and meat, potatoes, quinoa, salt and medicinal grasses were traded for maize, coca, firewood, fruit, oil and other goods from neighbouring regions.

Today, lorries have replaced the llama caravans of the past, but the system combining agricultural and non-agricultural activities has been maintained. Non-agricultural employment now includes urban business or artisan jobs, the civil service, mining and tourism (Figure 3) (Vassas Toral, 2011; Winkel, 2013). The new aspect is the growing – even predominant – share of family income generated by local agricultural production, thanks to the expanded international quinoa market. Although there are no regional statistics on the composition of family income, a survey conducted among 36 families in the area of the Uyuni salt flats shows the wide diversity of income depending on social status and, in particular, non-agricultural activities (Acosta Alba, 2007). For these families, annual earnings from quinoa production averaged nearly USD3 500 and reached a maximum of USD18 000, accounting for up to 70% of family income (ibid.). These figures are from 2007 – before the price of quinoa doubled in 2008. An independent survey in 2010 of 35 families in another community reported that most producers had an annual income of USD13 000 and that 11% of farmers with extensive farmland (> 30 ha) had an annual income of USD45,500 (Medrano Echalar *et al.*, 2011). Overall, the success of quinoa has meant that, in local farmers' household budgets, quinoa cultivation has supplanted animal husbandry in its traditional function of providing savings and insurance. Moreover, unlike livestock, quinoa does not require a continuous human presence in the production area; this facilitates the di-

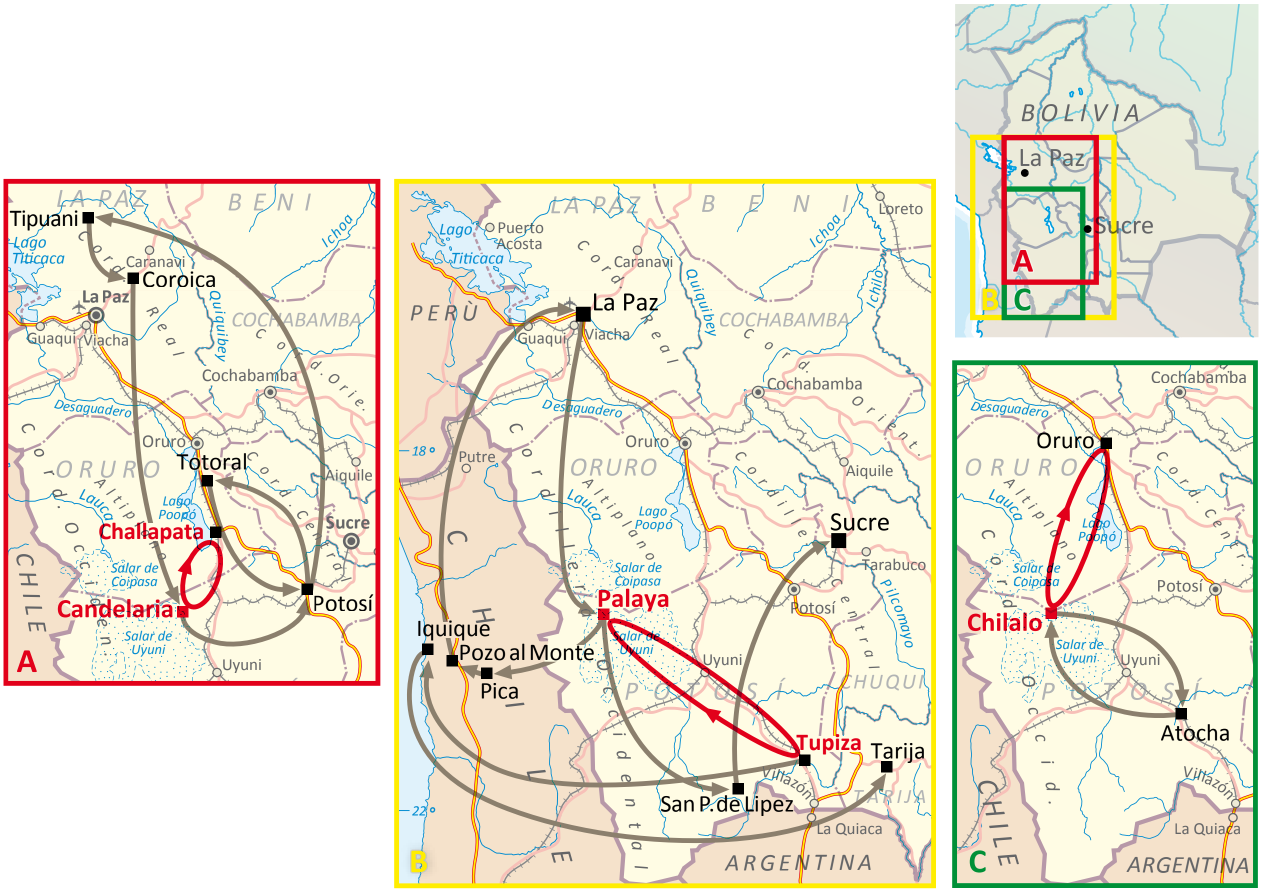

Figure 3: Examples of migratory paths for three quinoa producers in the southern Altiplano. Source: Vassas Toral (2011)

versification of family income through mobility and pluriactivity outside the production area (Chaxel, 2007; Vassas Toral, 2011).

The success of commercial quinoa production contributes to the integrated development of the region. The rural communities where the crops grow are linked with nearby cities where the producers settle with their families and where they invest most of their farming income: in the education of their children, in business or artisan activities, in the construction of houses or in the purchase of vehicles (Laguna, 2011; Vassas Toral, 2011). A comprehensive assessment of quinoa's economic contribution to the development of the southern Altiplano must be carried out, taking into account not only grain sales, but also revenue from industrial processing, related activities (e.g. agromechanics, transport), reinvestments, taxes etc. The revenue generated in this region solely through the sale of quinoa has been estimated at BOB360 million (bolivianos, approx. USD50 million) (2008 data, Aroni *et al.*, 2009).

Quinoa's current situation and prospects

For almost three decades, the development of quinoa production in the southern Altiplano received little support from official institutions. In contrast, during the last 10 years the 'Quinoa Real' boom has attracted the attention of numerous national and international support programmes and projects. Given the growing interest in a product emblematic of vigorous Andean agriculture, a series of working documents has been published by the AUTAPO and PROINPA foundations and are available online, in particular: a synthesis by Aroni *et al.* (2009) on the situation of 'Quinoa Real' in the region, and a more general report by Rojas (2011) in support of the declaration of 2013 as the International Year of Quinoa. An atlas of 'Quinoa Real' production has been published with satellite maps and statistics showing the main biophysical and socio-economic indicators in ten municipalities of the region (Fundación AUTAPO, 2012). The large amount of technical, social and economic data available in these documents cannot be detailed here. However, some of the information from the above-mentioned synthesis is presented below, followed by specific comments on the environmental and social challenges posed by the 'Quinoa Real' boom.

Quinoa in a few figures

In the southern Altiplano, quinoa is grown by 6 300 on-site farmers and 8 000 producers, whose primary residence is outside the community. Nearly 70% of production takes place on the plains. Sowing is mechanized in 76% of cases, while harvesting is almost exclusively manual. Indeed, only 2% of farmers use string trimmers. During the 2007/08 farming season, production totalled 28 000 tonnes from a cultivated area of approximately 49 000 ha, to which can be added 46 000 ha of fallow land. In Bolivia, domestic demand for quinoa is estimated at 7 000 tonnes per year. The value of reported quinoa exports has increased almost fortyfold in the last 10 years. Export volumes officially went from 1 400 tonnes in 2000 to 10 400 tonnes in 2008, and rose to 26 000 tonnes in 2012. After the United States of America (USD10.1 million for 4 095 tonnes in 2008), France is the second largest importer of 'Quinoa Real' (USD3.7 million for 1 700 tonnes in 2008). Bolivia has 62 quinoa processing plants, both artisanal and industrial, which contribute to the added value of quinoa within the country.

An agrosystem reaching its territorial limits

Annual quinoa production in the southern Altiplano requires a 2-year precipitation cycle and, therefore, two growing areas: the area where the crop is growing, and the area tilled for sowing in the following cycle. As cultivated areas are extended and concentrated, it is difficult for the natural *tola* vegetation to recolonize fallow plots, because its natural seed banks quickly become impoverished. The bare soil in fallow fields and in yet-to-be-planted plots remains exposed to the wind, which is especially strong in the Altiplano. Given the very slow regrowth of the native vegetation (Joffre and Acho, 2008; Medrano Echalar *et al.*, 2011), the conversion of large areas of grasslands into croplands constitutes an almost irreversible change in plant cover and hastens the process of wind erosion (Michel, 2008). Moreover, the areas recently converted into cropland are concentrated in low, flat areas that, because of cold air drainage at night, are more susceptible to frost than the surrounding hillsides (Pouteau *et al.*, 2011). Indeed, the frosts in 2007 and 2008 revealed the vulnerability of the quinoa agrosystem in these new production areas. Despite this, given the high selling prices of quinoa, farmers are willing to accept the economic risk of growing it in the plains.

Loss of soil fertility in land mechanically cultivated for quinoa is often cited mentioned as a constraint, as the main cause of a supposed decrease in quinoa yields and proof that the agro-ecosystem has exceeded its capacity (Cossio, 2008; Félix and Vilca, 2009; Jacobsen, 2011). A recent study of soil fertility in the area of greatest quinoa production indicates that 88% of soils have low to moderate fertility (Cárdenas and Choque, 2008). There are no data, however, to assess the impact of quinoa production on these fertility levels. The same study does not find any link between the quinoa yields in ten communities in the area and the average duration of land use (30–50years). In general, the "evidence" of accelerated soil degradation in the region lies in national statistics on grain yields. It should be noted that these data are aggregated at national level and cannot adequately characterize a local phenomenon such as soil fertility. Furthermore, they do not reveal a statistical trend indicating a decrease in quinoa yields over the last 50 years, including during the recent production boom, although a comparison with the previous period is possible (Winkel *et al.*, 2012). More importantly, grain yield is not an appropriate indicator of potential soil degradation, because the annual yield of a crop is the result of several concomitant factors aside from soil fertility: climate, agricultural practices and possible attacks by pests. In the case of quinoa in the southern Altiplano, the mediocre results of mechanized sowing (compared with manual sowing) and the frequent cultivation of crops on plains exposed to wind, frost and pests, are factors that may contribute to loss of soil fertility and explain the relatively low yields (500–700 kg/ha) usually obtained on the plains, when compared with the higher yields (1 000–1

500 kg/ha) obtained on mountainsides carefully farmed by hand and less affected by weather and pests (Winkel *et al.*, 2012).

Given the uncertainty regarding agronomic indicators of soil quality and their relation to grain production, the most tangible indicator of the agro-ecological limit reached by the current production system is the surface area of land converted to quinoa crops. In most communities, the land that can be worked by machine and converted into farming plots has already reached its limit. This has caused rising tensions among families about land access (Vieira Pak, 2012) and natural plant cover has been reduced (Michel, 2008). Aroni *et al.* (2009) estimate that, of the 145 000 ha of potentially arable land in the southern Altiplano, one-third is being farmed, one-third is lying fallow and the rest is "virgin land" (reserve areas, pastures, steep slopes etc.). Most producers do not keep areas of native vegetation for animal husbandry because it is not financially profitable. However, it is important to factor in the ecological benefits of such land, as these areas act as natural barriers to wind and water erosion, habitats for the natural predators of quinoa pests, and sources of uncultivated resources (e.g. firewood and medicinal plants). To reap these environmental benefits and ensure the sustainability of the agrosystem, it is recommended to maintain hedgerows and sow quinoa in beds or strips with the native vegetation (ANAPQUI, 2009; Michel, 2008).

As a result of current changes in the use of territorial resources, the quinoa socio-ecosystem is susceptible to inequitable land access and uniformization of the landscape. Aware of these vulnerabilities, farmers, peasants' organizations and the authorities in charge of land management have begun local consultation processes to implement new rules and regulations on the use of territorial resources.

Regulations needed for production and commercialization

Since the 1952 agrarian reform, which had only minimal impact on the southern Altiplano – an environmentally inhospitable region disregarded by large landowners – a myriad of rules and regulations on land access and use have been created. Local rules and customs, transmitted and enforced by aboriginal authorities, coexist with national laws passed by the Government. Collective rules, the product of public consultations, compete with conditions of power or oversight by companies or certification organizations. However, rules are rarely applied in a uniform way across the region, either because of a lack of consensus in the local population or due to a dearth of resources for their implementation.

In this context, the NGO, Agronomists and Veterinarians without Borders (AVSF, formerly VSF-CICDA), in coordination with the National Association of Quinoa Producers (ANAPQUI), set out at the beginning of the 2000s to establish new collective rules on territorial management adapted to recent changes in the agrosystem in several communities in the area (Félix and Vilca, 2009). After a long process of raising awareness and consultation with local stakeholders, technical and regulatory recommendations (both individual and collective) were proposed with the aim of achieving sustainable quinoa production in the southern Altiplano (ANAPQUI, 2009). A gradual participatory methodology was implemented, whereby local stakeholders seeking to overcome disagreements and conflicts could reach a consensus on the rights and obligations required to manage communal lands equitably and sustainably.

Uses and markets

The many traditional or novel uses of quinoa

The exceptional nutritional value of quinoa is well documented. In addition to its high content of proteins and balanced amino acids, the grain has high levels of minerals, anti-oxidants, unsaturated fatty acids and dietary fibre (Rojas, 2011; Soraide Lozano, 2011). Quinoa also offers multiple non-food applications: medicinal and ritual in its traditional forms, as well as chemical, pharmaceutical and cosmetic in its contemporary and industrial forms.

The versatility of quinoa makes it suitable for 35 different traditional food preparations, including soups, main dishes, pastries and drinks (Rojas, 2011). The populations living in the southern Altiplano eat quinoa in various forms: pearled, pilaf, ground, toasted and fermented (as the traditional drink called *q'usa*). Miners and peasants in the Altiplano use quinoa grains as food in rituals. Quinoa leaves are also consumed, for example in *yuyu*, a ritual soup prepared by regional stockbreeders for the llama festivities held between New Year's Eve and Carnival, when quinoa leaves are still tender. Quinoa stems are burned to ashes and mixed with other substances to make *lejía,* a kind of paste used to activate the alkaloids in the traditional consumption of coca leaves. Quinoa has a wide range of uses in medicine, which exploits all the plant parts (Rojas, 2011): it is used in plaster to treat bone fractures and is a recommended part of the diet during convalescence (Bonifacio *et al.*, 2012).

Non-traditional uses of 'Quinoa Real' have been encouraged in Bolivia since the beginning of the 1970s; events organized by Oruro Technical University have promoted Creole cuisine (Iñiguez de Barrios, 1977). Today, quinoa – in the form of flour, flakes or puffed grains – is an ingredient in numerous industrial products, including noodles, biscuits, energy bars and cereals manufactured inside and outside the country. These products are included in state school lunch and family food subsidy programmes. They also respond to the growing international demand for gluten-free food.

Domestic quinoa consumption has been the subject of various articles in the international press reporting an alarming loss of food security for local populations because of high prices and the profit motives of producers and exporters (Sherwin, 2011). The arguments presented, however, do not hold in an in-depth analysis of local eating habits, and they lack the historical perspective to assess changes in quinoa consumption dating back to before the current commercial boom (Banks, 2011; Winkel *et al.*, 2012). In particular, they are based on a comparison of the amounts of quinoa, noodles and rice eaten by local populations – a common comparison (e.g. Montoya, 2009; Borja and Soraide, 2007), but an inadequate one in terms of nutrition, because it is important to take into consideration quinoa's specific characteristics, notably its high protein and dietary fibre content. Local consumers know that they can be satiated with just a small quantity of quinoa (Rojas, 2011), and they therefore add only moderate amounts to soups and other dishes (Banks, 2011). Therefore, to compare quinoa consumption on a quantitative basis with consumption of other grains does not make sense: the two types of food do not have the same nutritional value or the same function in the human diet.

Important non-food uses of quinoa include applications employing saponin, a by-product from bitter quinoa grains, such as the varieties that make up 'Quinoa Real'. The detergent and cosmetic properties of saponin have long been known to local populations and are now recognized by industry. This by-product also makes a powerful bioinsecticide and, in pharmaceutical applications, an antibiotic and an effective adjuvant for the intestinal absorption of some medicines (Rojas, 2011). Lastly, some uses of quinoa for animal food and health should also be mentioned: as forage and to relieve altitude sickness in cattle (MDRyT and CONACOPROQ, 2009).

A diversity of markets and forms of commercialization

Although 'Quinoa Real' farmers and their families never stopped eating the "golden grain", the paradox of quinoa is that it was valued as a commercial resource outside the country many decades before it regained its lost recognition at home. The market dynamics for 'Quinoa Real' did not, therefore, follow a typical pattern, since exports grew before the grain regained its domestic market.

During the last 40 years or so of resounding commercial success, demand for 'Quinoa Real' has continued to grow. New kinds of demand have not replaced the old ones, but have simply been added to them. Production increases have kept pace with market diversification and evolving commercialization channels. The contraband market coexists with formal commerce, conventional quinoa with organic quinoa, and individual sales with private or group distribution. This situation prevents quinoa producers in the southern Altiplano from falling under the control of just a few trading companies, a common occurrence for other farmers in the world. Currently, more than 20 producers' associations and private companies store, process, transform and sell 'Quinoa Real' in Bolivia (Aroni *et al.*, 2009). These organizations and even the *rescatiris* – rural middlemen often stigmatized for taking advantage of the humblest farmers – have their operating methods and play their role in the economic system of 'Quinoa Real' (Ofstehage, 2010, 2012).

Aroni *et al.* (2009) describe in detail the various distribution systems operating in the southern Altiplano. 'Quinoa Real' is commercialized as follows: "some 43% through the informal sector, the Challapata open market or intermediaries who sell quinoa on domestic or contraband markets, and the remaining 57% is stockpiled by organizations to be sold to processing companies and exporters". More than 95% of quinoa exports are in the form of grain, most of which has organic certification and a smaller proportion fair-trade certification. There is also a growing demand for quinoa derivatives, such as flour, flakes, pastries, puffed quinoa, cereals and chocolate quinoa bars. This demand has enabled the development of a national industry capable of contributing to the expansion of the domestic market. Several products from this industry have been incorporated into government food subsidy programmes.

Questions and problems

'Quinoa Real' farmers in the southern Altiplano were forerunners and are now leaders in the cultivation of quinoa for export. After 40 years, their success is the result not only of continuous effort, but of constant adjustments to growing and ever-changing demand, thus demonstrating their great capacity for adaptation and social learning. Given the duration of the quinoa boom and the number of stakeholders involved, the questions and problems raised today have already been addressed in various studies: some focus on a specific subject such as genetic resources or soil fertility (Arce, 2008; Bonifacio *et al.*, 2012, Cárdenas and Choque, 2008; Michel, 2008); others seek to organize the available technical, social and economic information (Aroni *et al.*, 2009; Soraide Lozano, 2011); while others reflect more inclusively on socio-environmental issues and possible solutions (Cárdenas and Choque, 2008; Félix and Vilca, 2009).

Of all the subjects examined by researchers, land use is the most important and also the most widely debated in the media. Mechanization, insufficient fallow land and lack of fertilizer are presented as the causes of accelerated soil degradation, fuelling a vicious cycle of farming areas expanding to the detriment of pastureland. Nevertheless, there has to date been no published research demonstrating a clear, short- and long-term relation between quinoa production and soil fertility in the region. This lack of scientific research has not halted the discussion on soil exhaustion and the agrotechnical solutions to solve the problem. Many experts recommend systematically incorporating manure from camelids or sheep. This practice would undoubtedly foster animal husbandry and thus restore balance between agriculture and stockbreeding in the agrosystem. The impact of manure on soil fertility, however, appears very uncertain. Indeed, as Cárdenas and Choque point out (2008, p. 64): "the nitrogen content of manure is very poor and dynamic; also, the phosphorus and potassium are lost or are retained by mineral fractions [...]. The carbon-to-nitrogen ratio in manure is very high, so the degree of mineralization is very low, and it is difficult for the humus present to mineralize substances that accumulate in the soil." These conclusions are confirmed by Miranda Casas (2012) in his in-depth study showing a limited response of quinoa to manure fertilizer in non-irrigated plots, possibly due to nitrogen immobilization mechanisms in the soil. The author does, however, point out that the advantages of organic fertilizer may be indirect and the result of, for example, improvements to some physicochemical properties of soil, such as resistance to erosion and permeability. The potential benefits need to be evaluated under the agro-ecological conditions of the southern Altiplano.

In a similar vein, although recommendations to have hedgerows or to sow seeds in strips and beds for the prevention of soil erosion seem sensible, the effectiveness of such measures is yet to be demonstrated. Moreover, it is not certain that farmers, who do not all have the same access to land or the same economic capacity, would accept them. The option of returning to the ancestral system of *mantas* (the practice of alternating between farming and animal husbandry on communal land) seems too far removed from the current importance of quinoa production in the area and local economy. Indeed, the current circumstances cannot be compared to the situation that reigned before the commercial success of quinoa, when *mantas* helped to regulate soil fertility and maintain the equilibrium between farming and animal husbandry.

With regard to the excessive extension of cultivated areas, one solution is to intensify irrigated crops: farmers could produce greater yields in smaller areas and reduce the rate of expansion (CTPS, 2008). However, in a region with very scarce and often saline water resources, irrigation represents a serious threat to agricultural sustainability (Geerts et *al.*, 2008). Moreover, maintaining irrigation infrastructure in a region exposed to frequent frosts is technically challenging; ensuring equitable access to such costly infrastructure would lead to socio-economic problems. As with other innovations related to agricultural practices, systematized and comprehensive studies are needed, taking into account the local environmental conditions and the growers' specific socio-economic situations, with a view to the social and ecological sustainability of the agro-ecosystem (Cárdenas and Choque, 2008). On the whole, investments in intensive quinoa production in a region with environmental restrictions as severe as in the southern Altiplano are deemed very risky (Michel, 2008).

While the subject of land use has sparked great interest among various stakeholders (including promoters of lucrative agrotechnical solutions), the issue of land access was pushed into the background for a long time. The absence of formal rules led to an upsurge in quinoa farming, as inequalities among community members widened in terms of access to land; in some cases, conflicts were even generated within and between communities. As mentioned earlier, NGOs and producers' associations have addressed this sensitive matter, creating rules to achieve sustainable agricultural production. These communal rules on territorial management must be disseminated and effectively implemented to ensure a legal framework for land ownership and access. It would be interesting to examine how the usufruct of cultivated plots in a system of community land ownership has helped to protect community members against outside interests, contributing to the sustainability of the local agrosystem.

Similarly, the 'Quinoa Real' designation of origin process should be extended to protect local producers' access to their own seed resources. In this respect, a minor but important factor is the practical recognition of the diverse local varieties. Although their different food uses are appreciated, their agroecological characteristics are little known. Different "ecotypes" are mentioned without reference to the various responses of varieties to ecological factors such as soil and climate. This lack of knowledge hinders an understanding of the potential interactions between genotypes and the environment that have been observed in quinoa (Bertero *et al.*, 2004); this in turn invalidates efforts to differentiate the physicochemical characteristics and nutritive value of the varieties.

In addition to the problems related to land ownership, two other social issues should be highlighted. First, temporary migration, a very common practice among quinoa farmers, is sometimes blamed for irresponsible behaviour by some migrant producers who exploit and extract territorial resources. As demonstrated by Vassas Toral (2011), the social realities are more complex, and it is worth examining how the quinoa producers' system of mobility and pluriactivity contributes to the social sustainability and rural-urban development of the region. Moreover, given the farmers' capacity for adaptation and social learning, it seems pertinent to examine whether their responsiveness and adaptability would be affected by a proliferation of territorial and agrocommercial regulations. The key lies in the bargaining power and propositional force of the producers when they organize and take part in representative entities capable of self-transformation (Young, 2010). They are in apposition to prevent the excessive centralization of regulations and the privatization of their common property (Ostrom, 1990).

Conclusions

While gaps remain, there is now enough knowledge about quinoa production in the southern Altiplano of Bolivia to propose explanations for the four paradoxes characterizing the grain's commercial success. In some cases, these explanations can guide towards solutions to the challenges arising from the agricultural revolution experienced in the region over the last 40 years.

"A very special grain grown by unspecialized farmers": although quinoa benefits from niche markets, some of them very demanding and sophisticated, its producers continue to rely on agricultural and non-agricultural pluriactivity and mobility – two indispensable conditions for the economic sustainability of family farming in a regional context of great agroclimatic and economic uncertainty. Family strategies of pluriactivity and mobility are developed at the expense of animal husbandry. On the other hand, they foster integrated development between rural communities and medium or large cities in the region, thus reducing the need to migrate to distant urban centres.

"A productive crop in a harsh environment": recent studies have revealed some of the specific ecophysiological adaptations of 'Quinoa Real' varieties, for example, the vigorous root system enabling plants to explore the soil quickly and deeply and efficiently harness scarce water and nutrient resources. The aptitudes of these plants are complemented by the local practice of non-irrigated farming, resulting in farming methods that use very few artificial inputs (chemical fertilizers, fuel and pesticides). It is known, for example, that the 2-year fallow land system allows the soil to accumulate over 2 years the precipitation required to complete a quinoa farming cycle in this arid region. In contrast, the practice of sowing in holes has not yet received much attention in terms of its potential agro-ecological interest. The potential benefits are numerous, stemming from the optimization of the plants' water and nutrient use, resistance to wind, and tolerance of frost and pests.

"An organic, potentially unsustainable crop": it cannot be denied that, in some cases, unsustainable growing methods are practised in the region. This situation arose from an initial scarcity of knowledge about how to run large-scale commercial farming in an extreme environment with limited use of artificial inputs. Today, organic fertilizer, hedgerows and sowing in strips and beds are recommended strategies. Although their effectiveness is yet to be proved, these partial solutions should not be rejected. On the contrary, the problems they claim to solve must be considered on another scale. The structure of the rural landscape – i.e. the organization of the physical space encompassing crops, grazing land and natural areas – should be considered in terms of its multiple functions: preserving soils, controlling pest populations, balancing agriculture and animal husbandry, and providing benefits that are not strictly agricultural (e.g. firewood, medicinal plants).

"Sectorial dynamics requiring collective regulations": the development of quinoa agriculture began with a sectorial vision of the production chain of the crop that disregarded animal husbandry and natural areas. Over time, given the need for a consensus on equitable and sustainable land management, community members and quinoa producers' associations initiated various participatory processes to define new communal rules on land use. These same local rules were included in the 2012 revision of Fairtrade International standards to promote the sustainable production of quinoa, illustrating a successful example of bottom-up regulation: from grassroots to international bodies. As for the 'Quinoa Real' designation of origin, the regulatory process remains uncertain because of the complexity of the international procedures to ensure the rights of states and farmers over their plant genetic resources.

If the spatial structure of the rural landscape is considered together with the social aspects relating to land access, territorial organization and management emerge as the issues most requiring innovative solutions to deal with the unprecedented transformations in agriculture and local societies brought on by the quinoa boom of the last four decades. These organizational and social innovations should receive as much attention as agrotechnical ones on the agenda for the sustainable development of farming in the southern Altiplano.

Finally, it should be pointed out that the various solutions for the adaptability of the 'Quinoa Real' agrosystem in the southern Altiplano of Bolivia are related to the following:

- Plant material with an exceptional capacity to adapt to the environment and high intra- and intervarietal diversity. These qualities may be essential for an agrosystem requiring few inputs and providing a model for dry-farming in other mountainous and arid regions of the world. The biological characteristics of this plant material must therefore not be altered, nor should this collective heritage be taken from the control of farmers. The designation of origin could serve as a framework for this protection in the context of the accelerated spread of quinoa cultivation outside its Andean birthplace.

- A responsive and proactive local society exhibiting a high level of social learning based on several mechanisms for social cohesion: vigorous community customs and traditions, active associations and adherence to community landownership rules. Care should be taken not to fall into black and white judgements opposing migrant producers and on-site producers, farmers and stockbreeders, *rescatiris* and intermediaries, Lípez and Intersalar etc. Mechanisms for cohesion and social learning enable the local society to adapt to climate and market changes undreway in the region long before the quinoa boom (Banks, 2011). These factors also allow society to resist command-and-control trends and the agrotechnical and financial "packages" that are usually presented when an agricultural crop of economic interest emerges (Holling and Meffe, 1996; Briggs, 2003). These factors for social cohesion are the key to agricultural and food sovereignty for local populations and the country as a whole (De Schutter, 2011).

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