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MISCELLANEOUS

The Situation for Quinoa and Its Production in Southern Bolivia: From Economic Success to Environmental Disaster

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Abstract

In Bolivia, one of the world's most important centres of plant domestication, there is growing awareness of the value of native Andean crops, both for domestic consumption and for market sale – notably the virtually boom-like consumer demand for quinoa around the world. The southern altiplano of Bolivia, south of Oruro, relies almost purely on the production of quinoa and breeding of llamas, which have also been selected as the two commodities of priority to the government to increase the income of the country. Presently, however, quinoa is facing increasing problems in production, owing to its increasing export market and price. The flat areas around the salt desert of the southern altiplano, previously characterized by natural vegetation fed by the llamas, are being increasingly sown with quinoa, hence transformed into deserts, because intensive cultivation methods make the soil loose its fertility. Possible solutions to these problems will require extensive efforts in the south, in addition to various strategies, which also include other parts of the Bolivian altiplano and a strengthened focus on other Andean crops.

Introduction

Travelling on the Bolivian altiplano from the capital La Paz and southwards is a journey from difficult to even worse conditions. Agricultural production is taking place up to almost 4000 m above sea level, in an extremely harsh climate, because of drought and frost and other adverse factors, in the south with 200 days of night frost and only 200 mm of rain. Under these conditions, only one crop is grown, the quinoa (*Chenopodium quinoa* Willd.). This crop has been the main food for the Bolivian population that has survived on this highly nutritious food for thousands of years. Production for the international market began in 1983, when the national quinoa growers association (ANAPQUI) was established.

In the following, a description of the actual situation is given based on the authors' presence and work in the region for many years.

Bolivia

With a population of 9.1 million, Bolivia is the poorest country in the Andean region. In 2006, the annual income per capita reached USD 1153, with almost 40 % of the population living in poverty. Agriculture contributes roughly 15 % to the gross national product (GNP), but employs a much larger part of the population. However, the large majority of the population living in rural areas, which depends on agriculture, faces conditions of extreme poverty. Over 80 % of rural people in Bolivia live below the poverty line. Despite segments of high-input, export-oriented agriculture (e.g. soybean in the lowlands, sown on the expense of rainforest), much of the rural sector is focused on either subsistence farming or small-scale production for the domestic market, both of which have very low productivity. The alternative is to be engaged in coca production, with an alarmingly increasing area in Bolivia of 27500 ha in 2006 (ONDCP 2010), and probably much higher today (D. Cruz, personal communication 2010). Income in rural areas averages approx. USD 0.60 per day, one-third of the median urban income, and agricultural productivity is low (Janssen 2008).

Andes

Climate change is seriously affecting the country. The glaciers of the Andes are melting, which may create severe floods in the near future. It is estimated that Bolivia will lose 7 % of its GNP as a result of climate change (干Dideriksen 2008). The climate changes will particularly affect the Andean highlands and its indigenous population that is among the poorest in Bolivia (Viceministerio de Tierras, 2009). Life in the Andean mountains are harsh owing to extreme climatic conditions, the most common risk factors being drought, floods, frosts, hail and saline soils (Jacobsen et al. 2003a). Also, in these areas, the rural poor are often subject to political and economic marginalisation and ignorance with few options to improve their livelihoods.

The Southern Altiplano region of Bolivia is an extensive plateau located at an altitude that ranges from 3600 to 4100 metres above sea level. The plateau is surrounded by the Eastern and Western Andean mountain ranges that reach 5630 metres above sea level. The presence of the Uyuni Salt Flat with a surface of 12 500 km^2 defines many of the ecological aspects of the area. The area is characterized by an arid climate, with extreme temperatures that range from −11 °C to 30 °C. The number of frost nights is 160–257 per year and precipitation is 140–250 mm per year. The soils are composed mostly of volcanic ashes and lava and are very saline, sandy, with scarce organic matter (about 0.7 %), poor in nutrients and with low water and humidity retention capacity (Gobierno Municipal Salinas Garci Mendoza, 2006). The level of erosion is 4–30 % varying between zones and communities (CEPRODA 1999). The soils at the slopes contain more clay, organic matter and nutrients, than the soils of the plain areas (Joffre and Acho 2008).

Quinoa in Bolivia

The harsh environmental conditions of the Andes have required domestication of quinoa and other robust agricultural crops characterised by exceptional environmental adaptation, specifically to montane conditions with tolerance to drought (Jensen et al. 2000, Garcia et al. 2003, 2007, Jacobsen et al. 2001, 2003a,b,c, Bois et al. 2006, Geerts et al. 2008), frost (Jacobsen et al. 2005, 2007), saline soils (Koyro and Eisa 2008, Rosa et al. 2009, Ruffino et al. 2010, Jacobsen and Mujica 2003a, Hariadi et al. 2011) and other abiotic and biotic factors (Jacobsen et al. 2006a,b, Bertero et al. 2004). These Andean crops have yielded products of high nutritional value for millennia (González et al. 1989, González et al. 2009, 2010, Grau 1997, Gross et al. 1989, Hermann and Heller 1997, Repo-Carrasco et al. 2003, Jacobsen and Mujica 2003b). Today, unfortunately, genetic diversity in the Andes is under attack, threatened by desertification, deforestation, erosion and socioeconomic changes.

Traditionally, quinoa production was aimed at auto-consumption, and all practices like removal of shrubs after a long fallow period, ploughing, sowing in holes, application of manure, harvesting, threshing and cleaning, were manual. Within this system, the fallow serves different purposes. The most important is to store water in the soil the year previous to cropping, owing to the insufficiency of the annual precipitation to sustain production. In this way, quinoa uses 2 years of precipitation during its growth period. The second reason for the fallow is to restore soil fertility after harvest, and decrease incidences of pests and diseases. Taking into consideration the slowness of biological processes in these high altitude environments, this process needs at least 10 years (Joffre and Acho 2008).

Within the agrarian sector of Bolivia, quinoa plays a minor role. It is cultivated at less than 2 % of the total cultivated area and only 5 % of the cereal area in Bolivia. However, it is selected as the main commodity to improve livelihoods in the Andean region, together with the llama. The reason for its importance is that the southern altiplano of Bolivia, south of Oruro, relies almost solely on the production of quinoa and breeding of llamas, which have also been selected as the two commodities of government priority to increase the country's income. Quinoa is the most tolerant crop to the adverse factors seen here, and in addition, it is a food product of high nutritional value (Jacobsen et al. 2003a,b,c) .

In the last 20 years, quinoa production in the region has increased because of an enlarged production area, from 10 580 ha in the main department for quinoa production, Los Lipez, in 1980 to 20685 ha in 2001 (Chura 2009). Total area and production of quinoa in Bolivia has increased from 10 000 ha and 5000 t to presently 50 000 ha and a production of 25 000 t (Fig. 1). The first area increase was from 1970 to 1990, where quinoa was introduced to the planicie for the first time (Soraide 2008), which lead to a yield decrease in the same period. Production has been almost constantly increasing. In the 1990s, the area was stable and then the second area increase was seen from 1999 until today.

Simultaneously, with the last 10 years' area increase, yield has decreased from close to 700 to 570 kg ha^{-1} in 2009 (MDRyT 2009) (Fig. 1). The consequences of the significant changes in the Bolivian highland, such as the reduction in fallow period from 2–6 years to 1 or 2 years, is the progressive reduction in yield of quinoa over the last 20 years (Félix 2008).

Quinoa production has intensified because of increasing prices on the international market, causing its sustainable production to be in severe crisis. The price of quinoa sold by the farmer has almost tripled from 1999 to 2008, up to USD 2300/t (MDRyT 2009). This is three times the price of soybean and five times the price of wheat (La Razon, 29 September 2009).

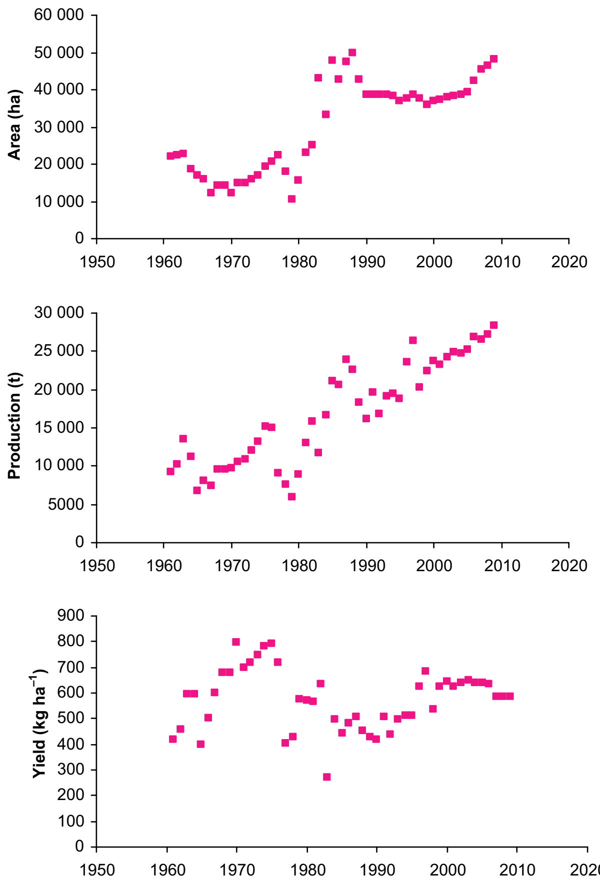

Fig. 1 Production area, production and yield of quinoa in Bolivia.

Export value of quinoa from Bolivia has increased from 2.7 mill. USD in 1999 to 8.9 mill. USD in 2006 (PNUD-Bolivia (Programa de las Naciones Unidas para el Desarollo) 2008). Export of quinoa has increased since 2001 whereas domestic consumption has decreased (Fig. 2). Ninety percent of the total quinoa production in Bolivia is now exported (Bolivia Rural 2010).

In this study, we will discuss how the development of an export market can have a negative effect on the environment and on home consumption of the same product. The aim of the study is to present the consequences of this situation and to discuss possible solutions to it.

Materials and Methods

This study is not to be regarded as an original scientific publication, as it rather is a reflection and presentation of the author's personal impression on the changes, which have occurred in the quinoa-producing area of southern Bolivia. The study is based on project work and regular visits to the region, when the author was employed at the International Potato Center (CIP), Lima, Peru, from 1996

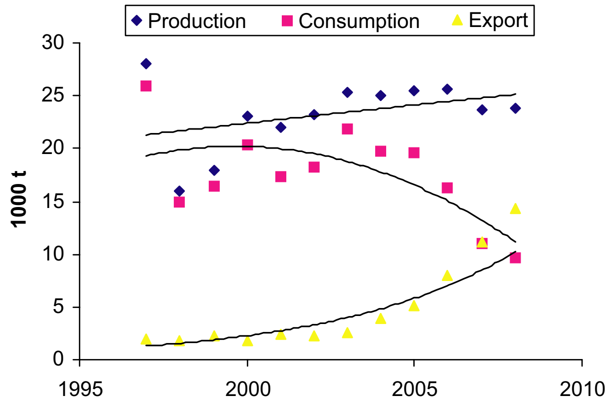

Fig. 2 Domestic consumption and export of quinoa in Bolivia, 1000 t (elaborated from MDRyT 2009). Lines are polynomic (production and consumption) and exponential (export).

to 2002, and as then in a private sector project BIO QUINUA, funded by the Danish government agency DANIDA, with the processing plant Andean Valley of La Paz, and the Danish bakery Aurion. Recently a new project on minor Andean crops (ANDESCROP) has been initiated (2010–2013), together with various institutions in Bolivia, with quinoa as one of the crops of the project. This project is funded by DANIDA research funds (FFU).

Results and Discussion

Main problems

It is obvious when entering the area around the Uyuni salt flat (the Salares) that something has changed. Previously the cultivation of quinoa, the only crop to be grown in the region, relied exclusively on manual inputs and was sustainable, but now several severe problems have arisen from a mechanised production system (Cossio 2008). The agricultural frontier has been extended, as virgin land on the planicie is being ploughed, drastically reducing the natural vegetation, and hence, the availability of feed for the livestock (Félix and Villca 2009). The increased use of tractors, especially with the disc plough and the sowing machine, has led to a severe degradation of soil fertility (PIEB 2009). There is a lack of organic manure, because there is still less natural pasture, so that the llamas have been moved to areas with no quinoa cultivation. Where llamas are still to be found, their manure is either not used or used erroneously, caused by a lack of knowledge of how to produce and utilize good manure. Instead fresh manure is used, which is detrimental to crop growth, because in the process of decomposition, the manure absorbs the limited soil humidity, and in addition, it contains weed seeds and disease spores. Development and dissemination of proper techniques for manure management is strongly needed.

The soils are degraded because of intensive management with no planning of adequate use (APSA II 2008). Hence, main problems in the south are soil degradation, disequilibrium between crop and animal production and reduced access to animal manure (Chura 2009).

Another problem detected is the destruction of the vegetation cover owing to incorporation of new areas for the production of quinoa, as this accelerates the process of erosion (FAUTAPO 2008). The natural vegetation cover is being reduced for the expansion of the agricultural border. The natural vegetation, apart from being used as pasture, is acting as wind breaks, hence its reduction has caused soil erosion to become severe, as seen from the increasing erosion incidents caused by the now unhampered winds removing upper soil layers. The situation is alarming as the altiplano is already in a process of desertification.

In 2009, the production of quinoa in the south of Bolivia, in the region of Lipez of Potosí, was threatened by a 50 % reduction because of drought, whose effect was worsened owing to the deterioration of the soils (El Diario, 13 February 2009).

The use of agricultural machineries, that is the disc plough and the sowing machine, has created an adequate habitat for various pests in the looser subsoil. After ploughing, the larvae of ticona (*Copitarsia* sp.) can easily enter the subsoil where it is protected from the irradiation of the sun. The larvae of polilla de quinua (*Eurysacca quinoa*) can complete its biological cycle, go into pupae stage and leave as adults (Rasmussen et al. 2003, Sigsgaard et al. 2008). There is a variety of herbivorous pests, such as larvae, rabbits, mice, rats, llamas, partridges, etc., which call for the application of integrated pest and disease control.

A range of unsustainable land use activities within the indigenous territories have caused accelerated land degradation (Bosque 2008). Among these are (i) expansion of the agricultural production area of quinoa, (ii) reduced area for the llamas, (iii) inadequate use of agricultural machinery, (iv) disappearance of natural vegetation such as the thola (*Parathrephia* spp., *Baccharis* spp., etc.) and (v) contamination from the mining industry.

The adverse effects of an unsustainable production of quinoa is even exacerbated by the climate changes, predicted for the Bolivian highland, that is higher temperatures, less precipitation and more extreme weather incidences. It may accelerate the desertification process and the degradation of land, which result in undesired impacts on the livelihood of the indigenous population and undermine the last decade's development efforts in the region.

The rising world market demands and the growing commercial quinoa cultivation is leading to land degradation caused by the intensified production of quinoa (Biodiversity International 2007; MDRyT 2009). Owing to the high prices of quinoa, farmers are changing their land use strategies towards a more intensive cultivation instead of an extensive production as described previously. The use of marginal lands, the use of inappropriate technologies and the fact that farmers are not leaving the land fallow as long as before are leading to wind erosion and nutrient depletion (PROINPA 2004).

Quinoa, which for thousands of years has been the traditional nutrition of Andean farmers, is now having such high value in the international market that farmers prefer selling it and buying less nutritious food for themselves (Hellin et al. 2004a,b, Hellin and Higman 2005).

The situation in the south is critical. An ecological disaster is threatening, turning the whole region into a desert, making it impossible to grow the only source available for food production and income generation among the rural population, the quinoa.

Certification system

There are large differences in the behaviour and quality of control between the certification bodies operating in Bolivia. Some has the reputation of being very strict, controlling all the farmers' fields, no matter how far the control person has to walk uphill. Others pick out a small sample of farmers from a certified association, and the remaining farmers are approved without any control. This may lead to the certification of non-existing fields and farmers, thus enabling export of organic quinoa which is not certified. According to the International Federation of Organic Agriculture Movements (IFOAM), the incorporation of virgin land in the production is in opposition to the basic standards of IFOAM. Certification bodies, accreditated by IFOAM, are forced to follow these regulations. This is not done at present. The problem could be reduced if the importers of EU and the USA put forward specific demands on cultivation methods and make sure it is controlled.

Political situation

The government of Bolivia has decided to support several complete processing plants to be distributed freely to farmers' associations, to enable them to export directly themselves. It is not realistic to believe that these associations will be able to export, as it requires high expertise. For the majority it will be a waste of money, which could have been used much better on other aspects in the quinoa production of high importance, such as building of small terraces, investment in micro-irrigation, fencing fields to keep out animals, improving technology for soil conservation and sowing, storage facilities, etc.

The Bolivian government has also decided to support the small-scale farmers of the southern altiplano with new machinery for the production of quinoa, which is very lamenting. Tractors to be offered to farmers' communities are jeopardizing the work looking for sustainable solutions to the increasing problems in the production of quinoa Real. The tractor may be a help in the work, but sustainability using tractors requires well-educated tractor drivers, who are able to distinguish between different soil types and their management, horizontal and vertical managing of the slopes and depth of soil.

Unfortunately, the government has not learnt from the negative consequences by using machinery, as the new plan for quinoa (MDRyT 2009) in the country mentions that one of the aims is to secure that the small-scale farmers have access to new equipment, tractors, etc. in the production of quinoa.

New equipment such as a sowing machine for sowing in holes must be developed. It is believed that the tractor has come to stay, so that its management should be optimized. Innovation in the sector is urgently needed.

Possible solutions

Several possible solutions to the range of problems developed through visits to the region, and interaction with national partner institutions, can be suggested.

Land and water management

One of the main problems is the degradation of soil fertility. This might be restored by changing soil preparation. Disc ploughing should be replaced by harrowing, ploughing with animals or chisel ploughing. Ploughing and harrowing of virgin land should be avoided, and practical courses for farmers in proper soil management and use of the tractor and various field operations should be offered, for instance by the newly established national system of agriculture, Instituto Nacional de Investigación en Agricultura y Forestería (INIAF). Incorporation of green manure from legumes that is the Andean lupin (*Lupinus mutabilis*), is being tested at present by PROINPA.

Sowing should be improved and plant establishment secured by the development of a sowing machine able to sow in holes, without opening the soil profile, or by using traditional manual sowing. Llama and sheep should be re-introduced, as organic manure is needed for maintaining soil fertility. An increased availability of manure would improve quinoa yield, and conserving soil humidity.

A focused deficit irrigation may be beneficial for an improved production of quinoa and eventually other crops in the southern altiplano. Where water is available for irrigation, a sustainable strategy for supplemental irrigation focused on the phenological phases where water is most needed should be considered. Supplemental irrigation is used in arid zones applying small amounts of irrigation water to crops that are normally grown under rain-fed conditions (Oweis et al. 1998). Deficit irrigation may reduce water use by up to 50 % of the amount used for full irrigation, but without reducing crop yield. Water productivity increases under deficit irrigation, relative to its value under full irrigation, as shown experimentally for many crops (Zwart and Bastiaanssen 2004, Fan et al. 2005, Fereres and Soriano 2007). Regulated deficit irrigation aims to only irrigate in drought-sensitive stages of growth with minimum amounts of water. A special form of regulated deficit irrigation is alternate irrigation (ARD), also termed partial root zone drying. With the ARD technique, the crop is irrigated at half of the root zone in turn, such as is the case in fruit trees (Kang and Zhang 2004), tomatoes (Kirda et al. 2004, Zegbe-Domínguez et al. 2003), soybean (Liu et al. 2003) and potatoes (Shahnazari et al. 2007). ARD is now being applied in the field, saving 20–50 % of the irrigation water. The physiological basis of ARD is that the intervention of chemical signals [abscisic acid (ABA)] from the dry side of the roots, leads to a closure of stomata at a certain level of stress, increasing water use efficiency (WUE) (Liu et al. 2005a,b, 2007). It was shown that quinoa had a sensitive stomatal closure during soil drying, by which the plants were able to maintain leaf water potential and photosynthesis, resulting in an increase of WUE (Jacobsen et al. 2009). Root-originated ABA played a role in stomata performance during soil drying. ABA regulation seemed to be one of the mechanisms utilised by quinoa when facing drought inducing decrease of turgor of stomata guard cells.

Drip irrigation systems including clogging-resistant drippers have been developed to save water resources and thus still more land should be drip irrigated worldwide in arid conditions the expense of furrow and sprinkler irrigation. Drip irrigation accounts presently for only little percentage of total irrigation, but with much potential to become more predominant. Martınez et al. (2009) mention that re-introduction of quinoa in arid Chile is feasible even under the prevailing conditions of low rainfall and deficient soils, but better yields will need some irrigation and addition of organic matter.

The situation in the southern altiplano is severe with decreasing water resources available. Micro-irrigation techniques could be a solution for improving food security. It is estimated by Centro de Promoción de Tecnologías Sostenibles (CPTS), La Paz, that with 200 wells, distributed over the southern altiplano, 1 mill. ha of new land can be cultivated in a sustainable way (C. Curi, personal communication, 2008). The cultivated areas will be irrigated with less than 10 m^3 ha^{-1}, that is in total 10 mill. m^3 $year^{-1}$. However, the competition for water is hard from the mining industry. It is estimated that the mining company in San Cristóbal consume 40 000 m^3 day^{-1}, that is 16.4 mill. m^3 $year^{-1}$.

It is important that an increased irrigation infrastructure is well organized to use the available water resources in a sustainable way, avoiding the loss of aquifers caused by overpumping. Also the irrigation must be planned accordingly to avoid salinization of the soil. It has been stated that supplemental irrigation is a highly efficient practice with great potential for increasing agricultural production and improving livelihoods in dry rain-fed areas (Oweis and Hachum 2006).

Ancestral techniques or new techniques relying on traditional knowledge such as micro-terraces, artificial lakes, high beds (suka kollos), etc. should be considered. Farmers' course in the preparation of compost and other organic manure is another important task.

It has not yet been studied if no-tillage is an adequate technique for the production of quinoa, in any case, it is necessary to turn the soil profile during the rain to break capillarity and hence save water for the sowing after half a year. The cropping system in the southern Bolivian altiplano is unique, so references on other crops from different conditions from other parts of the world are difficult to use and compare to the behaviour of quinoa. It was suggested in dryland farming to consider either a conservative or a more risky strategy depending on the distribution of dry and more favourable years (Sadras et al. 2003), however, in the southern Bolivian altiplano other options than quinoa are difficult, except when techniques like micro-terrazing and micro-irrigation are being applied.

Pests

Integrated pest control involves a range of pests. A possible control of rabbits and other animal pests is hunting. The rabbits live in between or under small rocks. As they come out after sunset to feed, hunting has to be performed at night using flashlight. After the first shot, the rabbits will run back to their holes, so the hunting has to be repeated several nights. Vegetation fences could be made from plant material or metal. The structure of the fence depends on which animal is seen as the main pest. Some animals are able to dig down under a fence, for instance rabbits, and mice and rats will be able to go through most fences. Birds cannot be kept out, while sheep, cattle and llamas need a strong and relatively high fence.

Fresh manure from llama or sheep, distributed in the crop, can be used as a repellant owing to its smell, and the use of traps is another option. The fox, which has been hunted excessively, and almost is extinct in the region, should be re-introduced, to create a better balance in the animal kingdom. Dynamite can be used to scare animals away, once is enough for some time, but the duration of the effect is unknown.

A combination of several methods should be used. Hunting at night with lamps may be efficient in some cases. Vegetation fences (barreras vivos) are very laborious to build, not very efficient and may require the cutting of natural vegetation (tholas). Fencing is very expensive. The simplest solutions may be to place traps in the field, for instance with a piece of mango fruit, which the rabbits seem to like, and to apply fresh manure on the plants as repellant. Some communities have used a piece of paper under a stone, which should scare away both rabbits and partridges.

Other production sites

Quinoa has a potential to be grown under a broad range of agro-climatic conditions in the Andes and outside the region (Jacobsen 2003). In the southern altiplano of Bolivia, quinoa Real is grown, which differs from other quinoa types by being adapted to the specific conditions of this area, and having large, white seeds, preferred on the export markets. Most of the quinoa to be found on the world market has been produced in this region. As the quinoa market is being diversified into other colours such as red and black, and processed products, there is no reason to use quinoa Real for these products. Therefore, the companies processing quinoa in Bolivia should use quinoa Real for whole, dehulled seeds, and other products from quinoa produced in the northern or central altiplano. Quinoa may also be grown in other Andes countries and outside Andes for instance in the African highlands and in Asia, and even in Europe it can be produced. A production outside the southern altiplano of Bolivia will decrease the pressure on the vulnerable region, and promote quinoa market when grown in a larger geographical region, of benefit for farmers in other parts of the world. The market potential for quinoa is huge (Jacobsen 2003).

New processing plants

Centro de Promoción de Tecnologías Sostenibles (CPTS) is an organization receiving funds from USAID and Danida, and previously from Swissaid, to develop improved equipment for processing plants of Bolivia, including all processes for cleaning, dehulling, washing, etc. They have sold the complete line of processing to the companies Andean Valley, La Paz; Irupani, El Alto; Quinoabol, La Paz; Cecaot, Uyuni; Anapqui, Challapata; and Cereales Andinos, La Paz. They are also able to adapt existing equipment, but most often they sell the entire processing line. The advantages are an optimization of efficiency with respect to the use of energy, water and quinoa raw material, a reduction of contamination, and an improvement of the quality of the final product. The nutritional quality of quinoa may have improved after installing the new processing equipment, because washing has a shorter duration (< 5 min) than before (c. 20 min).

Consumption

The farmers in the southern altiplano region, where the large seeded quinoa Real is grown for export, are no longer consuming their own quinoa, because of the high market value. Rather they are selling the quinoa on the market and buying products of less value, such as pasta and rice for their own consumption. Apart from the high market value another reason for preferring other food products is the work connected with the cleaning and dehulling of quinoa before consumption (Hellin et al. 2004b). The statistics confirm this development: The consumption of quinoa in Bolivia is only 2 kg per person per year, whereas the same for rice and pasta is 25 kg. Compared to Peru, where export is less, consumption of quinoa is more than 20 kg per person per year (Fig. 2).

Quinoa is a very good case study of an underutilized species that has been promoted for the market in a way that has not taken into account important social, environmental and health aspects (Astudillo in press). For the Andean farmer, quinoa played traditionally only a minor role in income generation, but it was extremely important in their nutrition, their social organisation and their environmental sustainability. Among quinoa-producing farmers, quinoa is now becoming displaced by modern western diets, which although easier to prepare are rich in simple carbohydrates and fats and poor in micronutrients. Data from household surveys have shown that the majority of meals during the survey time did not include quinoa at all, suggesting that perhaps quinoa is now becoming an underutilized food among quinoa producers. Quinoa demand shows an estimated annual increase of 0.08 % during the coming years, but the supply shows only an increase of 0.02 %. This leads to a projected deficit (Table 1).

The price has increased rapidly during the last decade (Table 2).

PROINPA (Promoción e Investigación de Productos Andinos) and other institutions are promoting a small mechanical dehuller. The small processing plant might be used to process a small part of the quinoa from the farmers, to return it as dehulled seed, ready to use for consumption.

A quinoa field with commercial varieties of quinoa Real for the market at the southern altiplano of Bolivia is shown in Figure 3.

General Discussion

The southern altiplano of Bolivia is experiencing a rapid degradation of its natural resources owing to unsustainable land use, which is likely to be worsened from the negative impacts of the expected climate changes. To prevent further erosion of natural resources, including the agro-biodiversity in the Andes, a conservation strategy must be formulated. Individual crops and their variability between regions, in addition to status, uses and cultivation methods by local farmers, must be studied.

Breeders of Andean crops – as of all crops – depend on trait variation in primitive and wild species to produce cultivars adapted to new environments and with higher and more secure yield. Thus, the need to rescue both local Andean biodiversity and local experience regarding agronomic and nutritional aspects cannot be overestimated.

Huge problems in the quinoa production are encountered on the southern altiplano. A number of soil fertility conserving practices already exist in the region, including use of animal manure and terrazing. The sustainability of

Table 1 Estimation of demand and supply of quinoa (PROQUIOR, 2008)

	2008	2009	2010	2011	2012	2013	2014	2015
Demand (t)	14566.28	15127.68	15689.08	16250.49	16811.89	17373.29	17934.70	18496.10
Supply (t)	11620.86	12195.74	12770.62	13345.49	13920.37	14495.25	15070.12	15645
Availability (t)	−2945.42	−2931.94	−2918.46	−2905.00	−2891.52	−2878.04	−2864.58	−2851.10

Table 2 Price development in quinoa, USD per 100 kg (elaborated from MDRyT)

Price quinoa, USD per 100 kg	2000	2002	2003	2004	2005	2006	2007	2008	2000–2008, % change
Raw conventional, informal market	28.4	34.1	45.4	51.1	56.8	68.2	73.8	204.5	620
Raw conventional, formal market	28.4	34.1	45.4	51.1	62.5	71.0	79.5	213.0	650
Raw organic, formal market	31.2	39.8	51.1	56.8	68.2	73.8	90.9	218.7	600
Processed conventional	–	105.1	–	–	79.5	79.5	113.6	255.6	143
Processed organic	–	125.0	–	–	113.6	113.6	122.1	261.3	109

Fig. 3 Quinoa field at the southern Bolivian altiplano.

the traditional management is under threat because of growing export markets that is increased mechanisation, leading to soil erosion; increased pest problems; diminishing use of animal manures and a more intensive cultivation. The options for diversification of the farming system and biomass production are limited owing to the harsh environmental conditions. Input of nitrogen to the system from legumes is not very realistic as a result of the limited performance of legumes on low fertility soils under drought stress, although it is being tested at the moment. Growing markets offer the potential for commercialization and increased use of inputs like manure, if this is available in sufficient quantities.

The combination of unsustainable land use and climate changes is unfortunate for many indigenous communities in the highlands. Development should be turned in the right direction, securing both a high value food like quinoa for the Bolivian population, and a resource for income to the Andean farmers, when satisfying global market demands in a sustainable way.

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