TECHNOLOGYCAL PROGRESS IN THE QUINOA SECTOR[♥]

Juan Cristóbal Birbuet[♦]
Carlos Gustavo Machicado[♣]

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Abstract

The main objective of this case study is to analyze the effect that the technology innovation in the quinoa processing had on the productivity of companies devoted to this activity, and the impact of such an innovation on the growth and organization of the quinoa cluster in Bolivia and its possible effects on the future. The study will explain how the boost engendered by the technological innovation in the quinoa processing triggered a series of events that allowed the establishment of an ambitious development program. The main companies and producer associations of the sector are part of this program, which is called "Quinoa Alliance". The program has become a unique opportunity of agro-industrial development for the Bolivian Altiplano, so far characterized by subsistence agriculture.

Keywords: Quinoa, saponin, unit operation, specific consumption, productivity.

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[♦] Centre for the Promotion of Sustainable Technologies (CPTS), e-mail: jc.birbuet@cpts.org
[♣] Institute for Advanced Development Studies (INESAD), e-mail: cmachicado@inesad.edu.bo

1 INTRODUCTION

This paper shows the role played by technological innovation in the productivity of Bolivian companies dedicated to the quinoa grain processing. It also shows how technological innovation favored the sectors growth and the creation and consolidation of an ambitious development program of which are part the main quinoa processing companies, producer associations and technology developers. Thanks to the results achieved by this program, which is called “Quinoa Alliance”, it has gained strength during the last three years. This allowed the Alliance to make a proposal of development for the sector based on the technological change of all links of the productive chain. This proposal, promoted by the private sector, was welcomed by the Bolivian Government for its soundness and wide-ranging approach for the development of the Bolivian Altiplano.

In order to establish the context of the study, it has to be said that quinoa is a unique grain in the world because of its excellent nutritional characteristics. It has an important content of high-quality proteins, a perfect balance of amino acids and it does not contain gluten. Due to these characteristics, quinoa is a complete food and in several senses unbeatable. In fact, it is considered to be, by several scientists, the best food in the world in addition to the fact that it is highly appreciated by international markets[1]. For all these reasons, quinoa was declared to be the Perfect Food for Humanity by UNESCO.

In spite of the exceptional characteristics of this millenarian grain, the world seems to have discovered it recently, which is why it has been called “the top secret super food”[2]. During the last years, the world quinoa demand rose significantly, this event has not precedent and was caused by three fundamental reasons which in a chronological order are: (1) the increasing demand of grains with no gluten content (at present 0.4% of the world population have the celiac disease[3]); (2) the accelerated growth of high-quality organic products demand together with the increase of the fair trade products market; and (3) the food efficiency programs which are being adopted by several countries with the support of the Food and Agriculture Organization of the United Nations (FAO).

Even though the quinoa demand is increasing rapidly, the offer of the sector has yet a limited capacity. Bolivia is one of the main quinoa agricultural producers in the world and being the only producer of the most appreciated quinoa variety, the “quinoa real”. However, the annual agricultural production of quinoa real is not more than 22,000 tons and has remained practically constant during the last ten years[4].

The quinoa productive chain has three fundamental links: (i) the agricultural production of the grain, (ii) the grain processing and (iii) the production of products with added value. Until three years ago, the main problem of the sector was located at the second link of the productive chain, the grain processing. In fact, the installed processing capacity of the companies dedicated to this activity was reduced and the technology used had low processing efficiencies.

Until the end of 2005, the installed quinoa-processing capacity in Bolivia was approximately 5,000 tons per year. That implied that there was only capacity to process around 35% of the grain agricultural production of that year. In addition, quinoa-processing companies had high quantities of product losses and the “saponin”, a sub-product of great commercial value, was not recovered. Nevertheless, during the last years, the quinoa cluster experienced great progress in processing the quinoa grain (the second link of the productive chain). In effect, a revolutionary technological change was adopted by six of the twelve most important companies of the sector which, jointly, are responsible of 80% of the quinoa exports in Bolivia. In three years, these six companies increased their processing capacity in 550%, improving simultaneously their productivity indicators.

[1] Recently, the NASA´s Controlled Ecological Life Support System (CELSS) program has chosen quinoa as their most promising crop candidate, due to its nutritional properties and plant growth characteristics (the CELLS concept will utilize plants to remove carbon dioxide from the atmosphere and generate food, oxygen, and water for the crew of long-term human space missions).

[2] Matt Goulding in an article of the magazine Men’s Health.

[3] Celiac disease is a disorder resulting from an immune reaction to gluten, a protein found in wheat and related grains, and present in many foods.

[4] In addition, around 8,000 tones of other quinoa varieties are also produced.

The boost engendered by the technological innovation in the quinoa processing triggered a series of events that allowed the establishment of an ambitious development program. The main companies and producer associations of the sector are part of this program, which is called “Quinoa Alliance”. The program has become a unique opportunity of agro-industrial development for the Bolivian Altiplano, so far characterized by subsistence agriculture.

The case study is organized in eight sections. Section 1 introduces the study. Section 2 describes the relation between the technological innovation that took place at the quinoa-processing link of the quinoa productive chain and the creation of the Quinoa Alliance. Section 3 presents the results of the mentioned technological innovation in figures. Section 4 refers to the process of diffusion of the new technology. Section 5 analyzes other elements, different from the technological, that might affect the productivity of companies. Section 6 explores the policies that were applied to promote the quinoa cluster in Bolivia. Section 7 describes the importance of focusing the Quinoa Alliance efforts on the quinoa agricultural production, and explains the effect that the recent technological advances can have on this link of the quinoa productive chain. Finally, section 8 presents the conclusions of the study.

2 NEW PROCESSING TECHNOLOGY AND THE CREATION OF THE QUINOA ALLIANCE

During the period 2001-2004, the Center for the Promotion of Sustainable Technologies (CPTS), a non-profit organization dedicated to helping industries meet challenges relating to sustainable development, carried out Cleaner Production (CP) assessments in five main quinoa-processing companies. These CP assessments were the basis to approach a more ambitious project, the development of new technology for the processing of quinoa, which established the foundations for the Quinoa Alliance formation.

Until the end of 2004, the CPTS had technically assisted companies of diverse sectors, but it had not designed or constructed any technology. The technical assistance aimed at optimizing processes in order to reduce the specific consumption[5] of materials, decreasing, simultaneously, the discharge of pollutants. Such goals were accomplished by the implementation of good housekeeping practices, the improvement of the existent technology or, in some cases, the substitution of equipments by others more efficient available at the market. Nevertheless, the situation of the companies processing quinoa required a special treatment. The technology used was highly inefficient and there was not any other better technology available at the market.

The major machinery and equipment manufacturers of the world did not produce custom technology for quinoa processing activity, and therefore this unique segment remained unattended. This arises because quinoa production is really small in comparison to other grains. As a result, there are not many companies in the world dedicated to the quinoa processing, and the market of specific technology for this sector is comparatively reduced[6]. It is most likely that the major technology manufacturers of the United States, Europe and Japan were not interested in investing R&D resources in a sector constituted by few costumers. Logically, they focused their efforts in developing technology for processing the most widely extends grains as rice, wheat or soy.

In view of that situation, the quinoa processing industries had to use adapted technology originally developed for the processing of wheat or rice with different production parameters and different production scales. The technology adaptation in such a conditions caused problems related to processing capacity and efficiency.

Without the appropriate production factors, and the lack of a specific combination of them, the quinoa sector had deficiencies to increase its processing capacity and add value to the product in competitive conditions. There was, consequently, a huge necessity of a better production technology locally

[5] The specific consumption is an indicator that expresses the amount of a material consumed per unit of production.
[6] Quinoa crops are limited to some countries which count with particular ecosystems.

developed, efficient, adequate to the needs and particular characteristics of the sector, and economically accessible to all quinoa-processing companies.

Thus how did CPTS decided to face a process of technological innovation? It was not indeed something planned, at least not at the beginning. As mentioned before, between 2001 and 2004, CPTS carried out CP assessments in five quinoa-processing companies (two in 2001, other two in 2003 and one in 2004). These companies were leaders in the sector and had a common feature, they used production technology highly inefficient originally design to process grains of different characteristics. It is probably that CPTS found its motivation to face a process of technological innovation since the first CP assessment carried out a quinoa-processing company, in March 2001. The company considered that its main challenge was the increment of its processing capacity in order to satisfy a growing market. The bottleneck was, in effect, the dry processing of the quinoa grain, step of the process aimed at eliminating impurities and reducing the content of saponins[7] by scarification.

The quinoa scarification was carried out in a peeler originally manufactured for rice scarification[8]. In such equipment, saponins were removed by friction, rubbing the quinoa grains against a metallic net. As the operation was slow, CPTS, tried, during the respective CP assessment, to find the maximum flow of quinoa that could be processed without diminishing the quality of scarification. After carrying out several trials with different quinoa scarification flows, it was discovered that the quality of scarification improved as the quinoa flow entering to the scarifier increased. These results revealed that scarification was accomplished not by rubbing the grains against the metallic net but by the friction among the grains themselves, the quinoa grains had, indeed, abrasive properties. The metallic net was, therefore, absolutely unnecessary in addition to the fact that it damaged the grain causing product losses. It was definitely an operation that used inappropriate equipment. This motivated a deeper revision of the technology.

After the CP assessments in the other quinoa-processing companies, where CPTS also evaluated the characteristics of the technology used, the necessity to embark on the development of new technology was more evident. The problems identified in the quinoa-processing companies can be summarized as follows:

- Significant losses of raw material (grain), with the consequent increment in the quantity of residues discharged.
- Low quality of the grain.
- High specific consumptions of water, electric energy and gas, with the consequent increment of production costs.
- Intensive use of labor force with the consequent increment of operation costs.
- Wastewater with high contents of saponins, with the consequent pollution of bodies of water.
- Impossibility of recovering pure saponin, with the consequent loss of its commercial value.

The main *causes* of these problems and the respective technological solutions that were proposed are explained as follows.

a) *Use of adapted technology in an inadequate manner for the processing of quinoa.* For instance, the use of rice peelers for the scarification of quinoa. This caused not only product losses, but also a loss of grain quality. To solve the problem, an efficient system of dry cleaning was designed, constructed and implemented. The system used the abrasive properties of quinoa for the scarification, through the friction among grains. In addition, a system of saponins recovery was installed in order to recuperate a sub-product that was wasted before.
b) Washing systems with a wide range of residence times. Quinoa-processing companies used washers with turbulent flows in order to accelerate the washing process and eliminate the saponin remaining at the grain. When water flow is turbulent, the quinoa grains exit the washer randomly. That is, the last grain entering the washer can be the first one in coming out of it, or the first one entering can be the

[7] Saponins, which are coating the grain, need to be removed as they confer a bitter taste to the grain. Nevertheless, saponins constitute a sub-product of high commercial value because of its fungicide applications.
[8] Other companies used fruits pulpers, sorghum peelers, etc.

last one coming out. This has two negative effects: (i) in the case of a short time of residence in the washer, the grains come out badly washed and have to be re-washed increasing, consequently, operation costs; (ii) in contrast, with a long time of residence, the grains are excessively humidified increasing the processing time, the energetic cost of drying, and reducing the product quality due to the dissolution of salts, proteins and starch in the washing water.

To come up with the solution of such a problem resulted in one of the most important innovations, the design of a washer which accomplished the simulation of a laminar trajectory of the grain, from a turbulent flow. This guarantees that the first grain entering the washer, is the last one in coming out. In addition, the system reduced the average time of residence in the washer, from 22 minutes to 4.7 minutes. The difference in efficiency between the old and the new washing systems is illustrated in Figure 1.

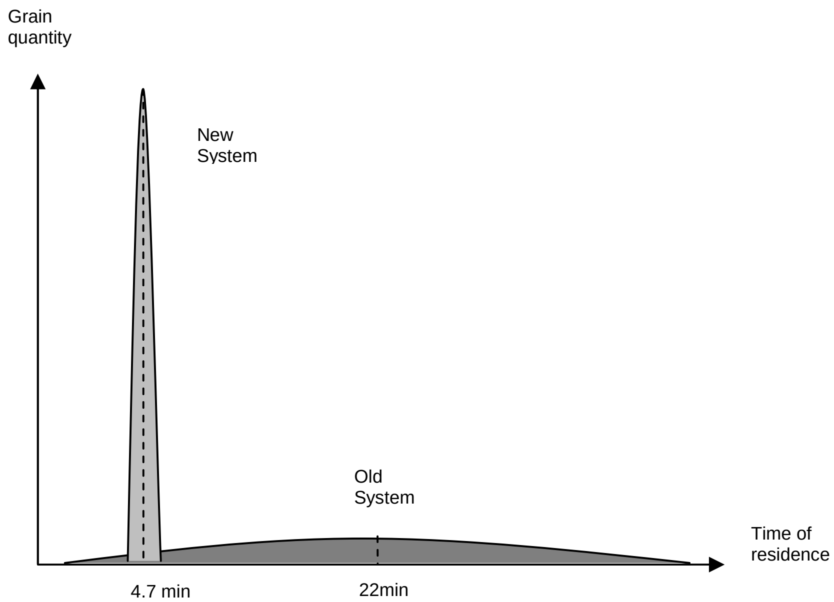

Figure 1 Optimization of the quinoa washing time with the new system
Source: CPTS

c) *Drying systems with insufficient air flows, which allowed the re-humidification of the grain in a significant percentage*. The new design of drying system is highly efficient. It employs a turbine which generates a great air flow with low energy consumption. The efficiency of the turbine is 76%, almost double of similar turbines efficiency manufactured in other countries[9].

d) *Use of technology that did not allow the recovery of sub-products with high commercial value*. For instance, the saponin, which has a high economic value at the market. With the ancient technology, the saponin was contaminated with impurities of the quinoa and particles detached from the quinoa itself. As a result, the price of saponin decreased in 70%. Moreover, in various cases, it was not possible to recover the saponin at all.

[9] The turbine has been patented by CPTS.

e) *Use of technology that operated in small batches (not in line, nor continuously).* For instance, the centrifugation operation was carried out in batches of less than 20 kg and demanded intensive labor force with exclusive dedication. The new technology operates in a continuous manner and demands few personnel.

f) *Excessive, and in some cases, unnecessary, number of unit operations in the process, with the consequent use of an excessive number of machines associated with each of the unit operations.* For example, after the washed grain drying and centrifugation, which count with a previous destoning system, and spite of the existence of a preceding operation of initial dry cleaning, the grain was cleaned again with various machines such as additional destoners, venting machines, optical system of colored particles selection and, finally, a manual system of impurities selection carried out by personnel exclusively dedicated to this. The new technology is more efficient in each of the steps of the drying and wet process; for this reason, there is no need of including additional cleaning unit operations after these processing steps.

The only way to solve the detected problems was, evidently, the development of a more efficient technology. The old technology was so inefficient that nothing was taken into account to design the new one.

In 2005, the United States Agency for International Development (USAID) granted funds for the execution of a demonstrative project aimed at designing and constructing an entire quinoa processing plant, based on Cleaner Production (CP) principles and adapted to the needs of the quinoa processing companies. The technology was designed by CPTS, constructed by Industrias Metálicas Andinas (IMA) and installed at Andean Valley SA (AVSA).

In 2006, the first prototype of the new technology started to work and increased the processing capacity of AVSA, from 240 tons/year to 1,900 tons/year. In addition, the technology reduced considerably operation costs of AVSA, which resulted in the increment of its cash flow and the improvement of its environmental performance indicators. The success achieved with the implementation of the new technology led the establishment of an alliance among CPTS, IMA and AVSA. The alliance aimed initially at consolidating the relationship of work that arose among these institutions during the development of the prototype. In a long term, the purpose was to focus the joint work in activities of research and development in the quinoa sector.

As soon as the diffusion of the technology began, other companies and institutions joined the alliance, which finally resulted in the establishment of the Quinoa Alliance. At the end of 2007, the installed capacity for the industrial processing of quinoa in Bolivia grew from 5,000 tons per year to 18,700 tons per year (see Figure 2). The increased installed capacity allows, at present, the industrial processing of about 85% of the total quinoa production. However, the gap of 15% between the processing capacity and the agricultural production does not mean that there are yet possibilities of increasing the processing capacity. In fact, not all quinoa grain can be industrially processed since producers consume one part of the quinoa and other part is used as seed for the next agricultural year. There is also an important quantity of quinoa that is sent illegally to Peru. Thus, with the current installed capacity, the companies have already difficulties in purchasing quinoa to process (raw grain). This deficit of agricultural production caused the increment of the price of the raw grain from 740 US$/ton in January 2007, to 2,300 US$/ton in June 2008. This increment in the price of 308% in a year and a half does not have precedents and is greater than those registered in other food in the same period. Clearly, part of the price increment is due to the greater demand of the quinoa grain caused by the increase of the processing capacity of the sector.

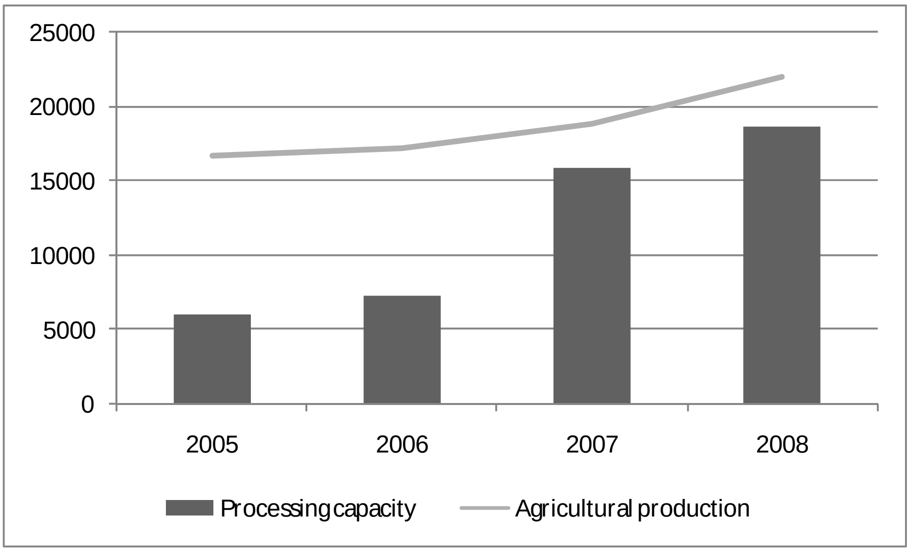

Figure 2 Quinoa agricultural production and internal processing capacity trends
Source: CPTS and National Institute of Statistics (INE, in Spanish)

Considering that the current processing capacity of the new production line (new technology) is 2,800 tons per year, the 100% of quinoa production could be processed with the installation of one additional production line. With the current orders of processing lines or technology, the global processing capacity could be up to 32,700 tons in a few months, that is, the installed capacity could exceed the agricultural production of quinoa real in approximately 50%. For that reason, the companies of the sector, even those that do not have the new technology yet, consider that the processing capacity problem has been solved to a large extent. At present, the technology supplier (IMA) can manufacture, in an average time of a month, a complete processing technological line with the capacity of processing the annual production of 5,600 hectares of quinoa (given the current crops yield) [10]. This implies that, in a short period of time, Bolivia could have an installed processing capacity greater than the agricultural production, which could result in severe negative impacts on soils sustainability.

In view of that potential situation, the members of the Quinoa Alliance defined a policy aimed at increasing the installed processing capacity concurrently with a sustainable augmentation of the agricultural production. This can be accomplished by changing the technological matrix of agriculture in the Bolivian Altiplano. Recent research and trials carried out in field show that it is possible not only to increase the crops yield significantly, but also to enlarge the agricultural boundary of the Altiplano in a sustainable manner, using lands that, during decades, were considered to be not suitable for agriculture. In fact, these lands resulted to be the best for quinoa cultivation. The quinoa sector development represents, nowadays, a unique opportunity of progress for all families of the poorest region in the country: the Altiplano.

The Quinoa Alliance includes, at present, six main companies of the sector, which jointly, are responsible of 80% of the quinoa exports in the country. The purpose of the Alliance is to promote a comprehensive development of the sector on the basis of technological innovation. In order to achieve this, a clear and ambitious objective was proposed: to increase the agricultural production of quinoa real from 22,000 tons per year to 1,000,000 tons per year in 15 years. Such a proposal, made by the private sector, was supported by all members of the Alliance and well received by the Government, which has included the quinoa cluster among the strategic sectors that must be supported in the framework of a productive development plan.

[10] At present, crop yields are around 500 kg of quinoa per hectare and the cultivated area of quinoa real is approximately 46,000 hectares.

Nowadays, the Ministry of Rural Development, Agriculture and Environment[11] and the Ministry of Development Planning[12] strongly believe that the Government intervention must be closely linked with proposal of the Quinoa Alliance.

3 THE TECHNOLOGICAL DEVELOPMENT IN FIGURES

The increase of the quinoa-processing installed capacity

As mentioned before, until three years ago, the main bottleneck of the quinoa cluster was the reduced processing capacity of companies. At present, the installed capacity allows the processing of almost all the agricultural production of quinoa with a great efficiency.

Table 1 shows the increment in the processing capacity of quinoa in Bolivia before and after the introduction of the new technology. It can be observed that, during the period 2005-2008, the installed capacity, in the six companies that changed their processing technology, increased in 550%. This contributed to an increment of 374% in the global processing capacity of quinoa.

Table 1 Installed processing capacity of quinoa in Bolivia

Company	Installed capacity before technological innovation [t/year] 2005	Installed capacity after technological innovation [t/year] 2008	Processing capacity increase [%]
AVSA	240	1,900	792
ANAPQUI	920	2,800	304
CECAOT	440	2,800	636
QUINOABOL	600	2,800	467
IRUPANA	600	2,800	467
CEREALES ANDINA	50	2,800	5,600
Installed capacity in the 6 companies	**2,850**	**15,900**	**550%**
Installed capacity in other companies **(*)**	2,150	2,800	32,5%
Total installed capacity	5,000	18,700	**374%**

(*) These companies do not have the new technology yet.
Source: CPTS

Thanks to the technological innovation that began in 2006, the companies were in better conditions to satisfy an increasing quinoa demand. During the period 1998-2007, quinoa exports increased in 747% but, it is since the year of 2006, that the slope of the exports curve increased significantly (see Figure 3). Such a considerable augmentation in exports coincides with the implementation of the new quinoa processing technology and shows the greater response capacity of national companies to the international quinoa demand.

[11] "Ministerio de Desarrollo Rural, Agropecuario y Medio Ambiente".
[12] "Ministerio de Planificación del Desarrollo".

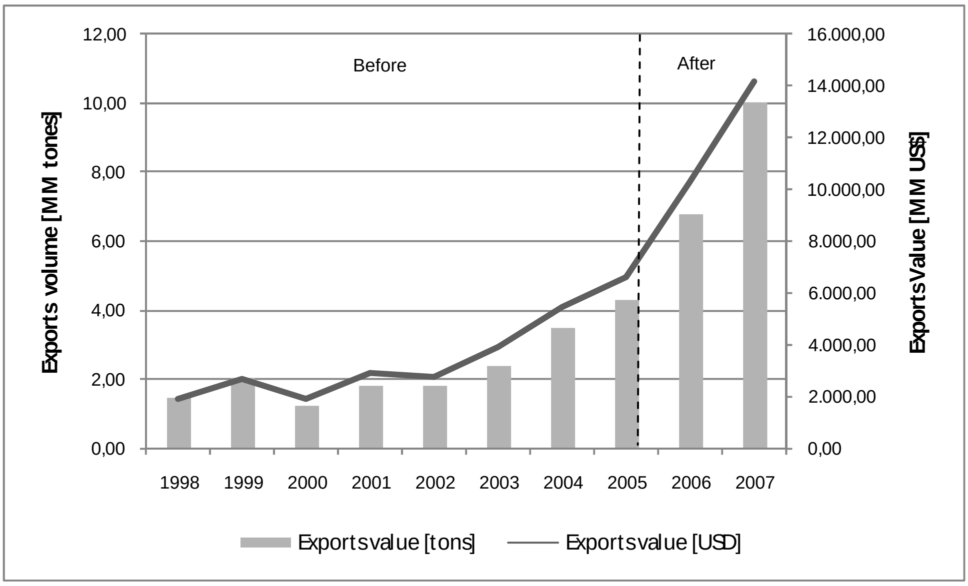

Figure 3 Quinoa exports from 1998 to 2007
Source: CAMEX (Cámara de Exportaciones)

As important as the augmentation of the processing capacity of companies and their greater response capacity to the increasing quinoa demand, was the increment of both inputs use efficiency and production factors efficiency. This was indeed a consequence of the implementation of a technology specifically designed for the quinoa processing under the criteria of Cleaner Production (CP). In effect, the new technology resulted in great economic and environmental benefits for the quinoa processing companies.

Increment of productivity and convergence

In order to illustrate the impact of the application of the new technology on productivity, various tests and measures were carried out in 3 representative companies which are responsible of 47% of the quinoa exports (IRUPANA, AVSA and ANAPQUI). Seven productivity indicators were used: (i) electric energy specific consumption, (ii) water specific consumption, (iii) thermal energy specific consumption, (iv) recovery percentage of saponin, (v) global yield, (vi) efficiency of labor force use, and (vii) efficiency of capital use. These indicators made possible the comparison of the efficiency levels before and after the implementation of the new technology.

Two main sources of information were the basis for the calculation of the first five indicators mentioned above: (i) material and energy balances, and (ii) material and energy consumption records. The material and energy balances helped in identifying the materials and energy that are exclusively consumed in the quinoa grain processing. This was needed for 4 fundamental reasons. First, because some companies process, in addition to quinoa, other food that also demand energy and materials. Second, because companies, besides the respective grain processing, add value to the grain (flour, flakes and pop quinoa). Third, because various companies do not register systematically the consumption of some materials or energy. And fourth, because some companies do not have records of the grain processing yields.

The information employed to calculate the efficiency of labor force use is related to the number of employees working exclusively at the grain processing line. We take the number of daily hours worked by these employees before and after the implementation of the new technology as well as the number of working days in each company per year. This information was gathered from the CP assessments and follow-up reports. In some cases, the companies completed the missing information.

Finally, the data used for the calculation of the indicator about the efficiency of capital use was the book value of machines and equipment, which has been provided by the companies. In contrast to the total value of fixed assets, the information related to the book value of machines and equipment allow us to determine and highlight, specifically, the changes in productivity associated to the implementation of the new technology. This fact is not clearly related to other assets. Moreover, some companies use assets like lands, buildings, vehicles, computers, etc, to support the quinoa processing as well as the processing of other food and therefore the attribution of the use of this type of assets to only the quinoa production is extremely difficult. That is why these assets were not taken into account.

Table 2 shows the productivity indicators before and after the implementation of the new technology in IRUPANA, AVSA and ANAPQUI. Definitely, the technological innovation improved all productivity indicators in the 3 companies without exception.

Table 2 Productivity indicators

Productivity indicators	IRUPANA		AVSA		ANAPQUI	
	Before	**After**	**Before**	**After**	**Before**	**After**
Electricity specific consumption [kWh/ t of processed grain]	58.26	32.8	94.7	44.7	78.2	42.1
Water specific consumption [m^3/t of processed grain]	12.8	8.65	14.0	6.0	9.7	4.5
Thermal energy specific consumption [Mcal/t of processed grain]	505	113	354	104	177	114
Saponins recovery [t of saponin/t of raw grain]	0.0	0.045	0.0	0.039	0.0	0.052
Global yield [tons of processed grain/t of raw grain]	0.835	0.901	0.918	0.936	0.785	0.902
Labor force use [man-hours/t of processed grain]	160.0	44.4	180.0	39.6	277.0	47.0
Capital use [USD of machines and equipment/t of processed grain]	184.0	75.3	215.7	150.0	418.1	204.4

Source: IRUPANA, AVSA, ANAPQUI and CPTS

It is worth to highlight that the increase in productivity came along with a convergence process of the productivity indicators (see Table 3). The reasons for such a convergence are: (i) the subsititution of batch operations by a continuous process, and (ii) the exhaustive technical training provided to the employees when the new technology was installed. This training allowed the “homogenization” of the operations management through procedures of parameters control and the establishment of production protocols. Before, no norms or procedures were followed.

The standard deviation is used as dispersion measure of the inter-company productivity. Table 3 shows its value before and after the technological change[13]. With the exception of the water specific consumption indicator, all productivity indicators show a lower inter-company standard deviation after the implementation of the new technology. This indicates a greater convergence in the productivity of the sector.

[13] The dispersion measure was applied to all productivity indicators with the exception of the one related to the recovery of saponin because the saponin was not recovered before the implementation of the new technology.

Table 3 Convergence of productivity indicators

Productivity indicators	Inter-company Standard Deviation before the new technology	Inter-company Standard Deviation After the new technology
Electricity specific consumption [kWh/ t of processed grain]	14.9	6.3
Water specific consumption [m^3/t of processed grain] (*****)	1.8	2.1
Thermal energy specific consumption [Mcal/t of processed grain]	133.8	5.8
Global yield [tons of processed grain/t of raw grain]	0.05	0.02
Labor force use [man-hours/t of processed which grain]	51.1	3.75
Capital use [USD of machines and equipment/t of processed grain]	103.7	64.8

(*) The increase in the Inter-company Standard Deviation is due to problems in the lay out of the new installations of one of the processing companies.
Source: CPTS

4 THE DIFUSION OF THE TECHNOLOGY

The demonstrative workshop

The diffusion strategy consisted of a demonstrative workshop carried out in AVSA (Andean Valley SA), where the first prototype had been installed. The objective of the workshop was to show the technology working and the benefits implied in terms of: (i) the increase of the processing capacity, (ii) the materials and energy specific consumption reduction, (iii) the recovery of saponin as sub-product, and (v) the reduction of pollutant discharges per ton of quinoa processed (specific discharges).

A few weeks after the workshop, four companies placed their formal orders to purchase the technology. The only problem was that IMA (Industrias Metálicas Andina, the technology manufacturer) could construct a complete line of quinoa processing in no less than 8 months and no other manufacturer had the adequate technical capacity to produce components of precision. This meant that the last company would receive the technology after 2 years and 8 months. For that reason, IMA re-invested the money earned with the first technology in the expansion of its infrastructure and the hiring and training of new personnel. Nowadays, IMA is the main technology supplier for the quinoa sector and can construct an entire quinoa processing line in an average time of a month.

The temporal suspension of the technology construction

In 2008, CPTS and IMA suspended temporarily the production of the technology even if there was yet an unsatisfied demand for this machinery. Actually, it was not convenient to construct new quinoa processing lines without creating the conditions to augment significantly and in a sustainable manner, the agricultural production of quinoa. This implied an almost exclusive dedication to the development of agricultural technology, keeping active only maintenance services for the quinoa processing technology that had been already installed. Thanks to economic resources from the international cooperation, CPTS and IMA could carry out the activities related to the research and development of the quinoa agricultural technology. Those resources compensated, to a certain extent, the income related to the sales of the quinoa processing technology that was not being received.

It is important to underline that, with the already installed capacity; almost all the quinoa agricultural production could be processed. As a result of the lack of sound agricultural technology, several producer communities adopted desperate but not sustainable measures to augment the agricultural production[14].

[14] Among the inadequate practices adopted by the producers as a result of the lack of sound technology, we can mention the reduction of the soil rest period and the use of inadequate technology (e.g. the use of disc plows).

Even if this behavior is comprehensible taking into account that in the southern part of the Altiplano the quinoa agricultural production represents around 50% to 85% of the total income of the producer families[15] and the increment of the demand and prices of quinoa was a great incentive for the cultivation of this product, it is also truth that these practices did not result in a significant increment of the quinoa agricultural production. In contrast, these reduced the soils productivity and compromised their sustainability in a medium and long term.

It is worth to remind that the agricultural production of quinoa is about 22,000 tons per year and that each new quinoa processing line can process around 2,800 tons of quinoa per year. The augmentation of the processing capacity as a result of the technological change was, therefore, exerting an additional pressure over the soils employed traditionally for this crop. Evidently, it was not correct to continue the installation of new processing lines without solving the agricultural problem. To increase the agricultural productivity is indeed a great challenge of the quinoa sector.

5 OTHER ASPECTS THAT HAVE AN INFLUENCE ON THE QUINOA COMPANIES PRODUCTIVITY

In addition to the technological change, other factors can influence the productivity of the quinoa processing companies. Some of those factors or elements are mentioned as follows.

The different types of companies

It is important to analyze the influence that the different forms of ownership have on the productivity of companies. Accordingly, two types of companies will be distinguished: (i) those in which the quinoa producers have ownership rights, which allow them to receive part of the profits (social companies), and (ii) companies in which the quinoa producers do not have any ownership participation; they are only quinoa suppliers (private companies). It has been noted, for example, that the market and the public policies discriminate positively the social companies. Five fundamental aspects differentiate the two types of companies:

1. Social companies have a board, constituted by the quinoa producers, which has administrative functions. These companies set control systems that are more strict and complex than those of private companies. In order to get the support from the associated producers in any decision made, the board must arduously "socialize" the decision in order to obtain acceptance. This can result in decisions not taken in time, which can be negative in a rapid changing context. On the contrary, private companies take decisions more rapidly and efficiently.

2. The board in social companies, in contrast to private companies, is not stable. The correspondent statutes oblige to change the board every two years. In some cases, the board can remain for one or two additional years if the management has been exceptionally outstanding. Nevertheless, this is rare to happen.

3. The use or application of profits in social companies is defined in the statutes. That is why there is not much flexibility in deciding the best use of those profits. An example of profits distribution in a social company is given as follows:

25%	Social Fund (for the retirement pensions of producers)
10%	Training
10%	Operations capital (raw quinoa purchases)
27.5%	Investment capital
13.75%	Regional organizations
13.75%	Associated producers

[15] According to Brenes, Crespo and Madrigal, 2001.

4. The academic background of the board and the personnel in social companies is not optimal. There are actually better prepared people in private companies. For this reason, the management in social companies is less efficient. This resulted in the loss of market segments which have been covered by private companies.

5. Social companies, in contrast to private companies, are vertically integrated. Private companies can not include the agricultural link into their value chain by law. The land belongs to the producers or is considered as communitarian, and according to the law, these can not be sold to private companies. In contrast, the producers own the social companies and the lands, or have the right to use them because they are part of the community. In view of that situation, private companies developed strategies to strengthen the relationships with their suppliers, who are the independent producers that are not associates in either of the social companies but have exploitation rights of their lands.

The fair-trade effect

Some markets tend to favor social companies, with better prices through the “fair-trade” practice. Until three years ago, quinoa-processing private companies could not accede to the fair-trade mechanism. In that time, the market price was approximately 1,000 US$ per ton of processed quinoa, and the fair-trade price was about 1,500 US$ per ton.

Undeniably, social companies benefited from this impressive difference in the price (50%). However, several private companies consider that during the period they could not accede to the fair-trade mechanism, their role with producers was similar to that of social companies. They also assert that, in most of the cases, the price that they paid to the quinoa producers (farm-gate price[16]) was superior to that paid by social companies that benefited from the fair trade.

The fair trade also created some distortions within some producer associations because of the small scale transactions which are characteristic of this market. In effect, social companies had to choose the producers that were going to benefit from the fair price as the demand of the fair-trade market was not as big as the offer of all associated producers. This caused various conflicts in the social companies, first, because there did not exist clear mechanisms for determining the producers that were going to be favored with the fair price, and second, because there was a lack of compensation mechanisms for those producers that could not accede to the fair price and that demanded a “fair” and similar treatment, in their quality of associates.

Some time ago, the fair-trade market opened its doors to private companies. Some of these companies began to prepare all the necessary requirements to get the respective certification. However, with the increase of the quinoa price, in 2008, the fair-trade market was not attractive any more. According to several companies, the fair trade incentives disappeared when the ton of processed quinoa exceeded the value of 1,600 US$. Ironically, when this happened, the respective negotiations of the price increment were more difficult with the “fair clients” than with “normal clients”.

Figure 4 shows the increase of quinoa farm-gate and FOB prices during the period 2007-2008. As observed, the farm gate price reached the value of 2,300 US$ per ton, and the FOB price, 3,100 US$ per ton, almost double of what the fair trade paid a year ago. In March and April 2008, the farm-gate and FOB prices were practically the same. However, since May of that year, the Bolivian quinoa companies negotiated other prices with their international clients. Currently, the difference between the farm-gate and FOB prices reached a historic maximum. This implies that the Bolivian companies re-negotiated the price efficiently.

[16] Término empleado en comercio justo para indicar el precio que se le paga al productor.

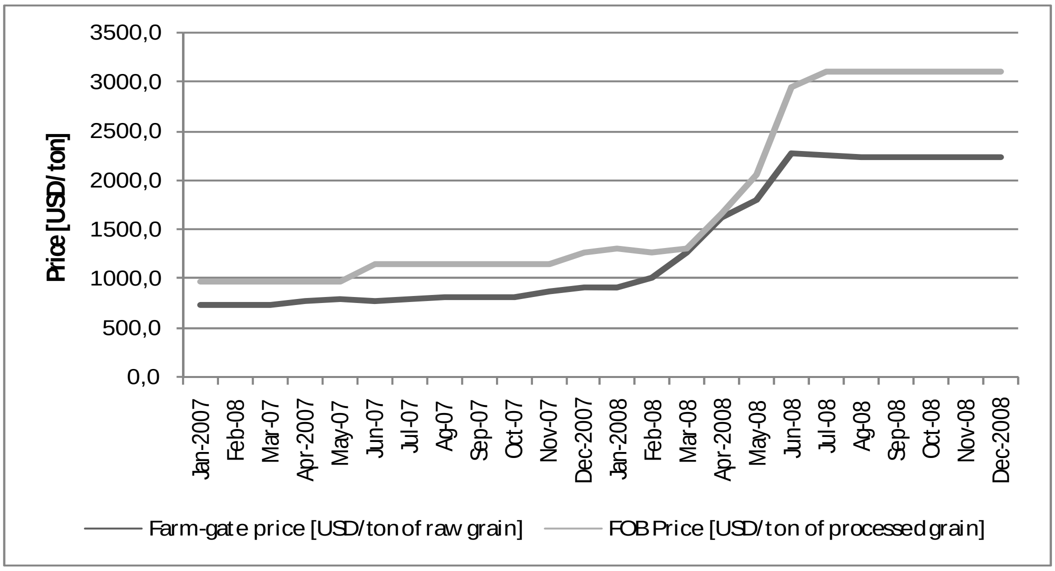

Figure 4 Farm-gate and FOB prices of quinoa from 2007 to 2008
Source: Members (companies) of the Quinoa Alliance

Asymmetry of information 1:¿ which is the most convenient color?

If the quinoa grain was valued only by its nutritional properties, its color (appearance) would not be of importance. However, the farm-gate price varies according to the color of the quinoa grain.

There are three colors of quinoa grain (real): white, red and black. The most known and abundant variety is the white quinoa. In European and US supermarkets the prices of the red quinoa and the black quinoa are, respectively, 42% and 51% greater than the white quinoa. Nevertheless, in Bolivia, the quinoa farm-gate prices are defined in an opposite sense to the preferences of the world consumers. In effect, the Bolivian producers offer the red and black quinoas at a price 40% lower than the price of the white quinoa. The reasons for the establishment of such prices are unknown.

Apparently, the consumers are willing to pay more for the red and black varieties since these are more exotic. The social companies are not aware of this; apparently, their international clients did not inform those preferences to them. The social companies pay, therefore, lower prices to their associates for the most appreciated quinoa, and they also export it at lower prices.

The private companies, in contrast, are better informed about the preferences of the international market and, during many years, negotiated a greater price when they sold the red and black quinoas to their international clients. In 2008, the export prices of the white, red and black quinoas were the same as a consequence of the significant increment in the general prices of the quinoa, which made impossible to charge, in addition, an extra price for the colored quinoas. However, as the farm-gate prices of the colored varieties are lower than international prices at supermarkets, the private companies are capable of obtaining a greater margin of benefits when they commercialize red and black quinoas.

Asymmetry of information 2: ¿to whom is expensive the quinoa real with organic certification?

According to the Bolivian companies, quinoa is a product with a greater price than other products that compete in the organic market. It was then a great surprise when, in 2008, the international clients continue to increase their orders even when prices rose. However, in Europe and the USA, the product quinoa does not have a greater price to the final consumer than other organic products. At supermarkets, the same retail-price is paid for other organic products. For instance, half kilo of quinoa, half kilo of beans or half kilo of lentils are sold at the same price to consumers.

In addition to covering the international demand, the Bolivian quinoa companies pursue the challenge of spreading massively the local quinoa consumption. So far, the public incentives for the internal quinoa consumption were focused on specific programs as the school breakfast or the Army food. In effect, those policies did not achieve a massive internal consumption of quinoa.

Comparatively, it is more expensive to eat organic quinoa in Bolivia than in Europe. For instance, a liter and a half of Coke, in Europe, costs approximately 4 US$, and half kilo of quinoa, 4.9 US$. That is, half kilo of quinoa is 22.5% more expensive than 1.5 L of Coke. In Bolivia, on the contrary, 1.5 L of Coke costs approximately 0.85 US$, and half kilo of quinoa, 2.5 US$, that is, 290% more expensive than 1.5 L of Coke. Evidently, in Bolivia, it has been easier to spread massively the consumption of Coke than of organic quinoa.

On the other hand, the GDP per capita in Bolivia is 3.7 US$/day, while in Europe the average GDP per capita is over 100 US$/day. It is then easy to understand why the major part of the quinoa real is exported. The sole approach to be deployed in order to have more quinoa available in the internal market at more accessible prices is to increase, in a sustainable manner, the agricultural production. This indeed requires a better technology, human resources well trained and efficiently organized, and proper infrastructure.

6 POLICY CONSIDERATIONS

The coordination among the development actors

The design and application of development policies for a sector requires the coordination of different public and private institutions. In the case of the quinoa sector, the role of articulation was played, at the beginning, by the Competitivity and Productivity Unit (UPC in Spanish[17]), a decentralized institution of the then Ministry of Economic Development, created in November 2001. The UPC worked on the strengthening of the productive sector through the coordination and consensus of the public, private and academic sectors, suggesting public policies reforms and proposals to achieve productive development[18]. The UPC made the first articulated attempt of public policy for the sector, including the contribution of all actors involved. The members of the Quinoa Alliance were among them; they participated actively in the design of the intervention plan.

The UPC involvement with the quinoa sector began in 2001, with the identification of priority sectors for action. The UPC applied a comprehensive approach of productive chains. It prepared twenty case studies of productive chains and prioritized eight; the quinoa productive chain was one of the selected given the high development potential implied. The next step involved the creation of the Committee of Quinoa Competitiveness, which was followed by the signature of the Bolivian Agreement for Competitiveness (ABC in Spanish[19]) among the actors concerned. The first ABC of the quinoa was signed in 2002, and the second in 2004. For the first time, the public interest in supporting the Bolivian quinoa productive sector was explicitly expressed, articulating all relevant actors.

After the ABC signed in 2004, a working agenda, named the Agenda of Shared Responsibility (ARCO in Spanish[20]), was defined. The Agenda established all activities to be carried out by each of the actors, the respective deadlines and the correspondent performance indicators. It was divided in 6 areas: (i) Infrastructure and Logistics, (ii) Management Quality and Human Development, (iii) Legislation, Norms and Procedures Simplification, (iv) Foreign Trade, Exports Promotion and Incentives for the local consumption, (v) Science, Technology and Innovation, and (vi) Financing and Access to Loans.

The program was ambitious and its deployment demanded not only great quantity of resources, but also a good level of articulation among the Government, Prefectures and Municipalities. Their role was mainly

[17] UPC: Unidad de Productividad y Competitividad.
[18] Nowadays, the UPC is a decentralized unit of the Ministry of Development Planning, created in 2006.
[19] ABC: Acuerdo Boliviano de Competitividad.
[20] ARCO: Agenda de Responsabilidad Compartida.

the construction of physic infrastructures and the provision of basic services at the areas of quinoa production.

Although the quinoa productive chain identified the most important areas of action and planned concrete activities, something essential missed: the definition of a clear and common objective. In our opinion, this resulted in the non-consolidation of the proposed plan and the disarticulated operation of the actors involved.

Areas of intervention at the quinoa productive chain

In the area of ***Infrastructure and Logistics***, the plan was specially focused on road infrastructure at the producer zones, prioritizing the construction and/or improvement of roads and the construction of bridges. This was aimed at reducing the quinoa transportation and commercialization costs. In relation to energy, the plan prioritized the improvement and extension of power lines, the construction of hydro power plants, and a strategy to guarantee the access of diesel to the production zones. The objective was to reduce the quinoa processing costs and mechanize the production activities of the southern part of the Altiplano. Finally, the Agenda included the development of projects aimed at providing irrigation infrastructure to the production zones, with the objective of increasing the yield of crops. The institutions responsible of executing these activities were mainly, the Prefectures of Oruro and Potosí and some small Municipalities that had scarce resources but counted with the support of the Social and Productive Investment Fund (FPS, in Spanish[21]). In 7 years, the accomplishments in terms of infrastructure are limited and disarticulated from the quinoa ABC.

The area of ***Management Quality and Human Development*** was focused on the strengthening of the organizational and managerial capacity of the quinoa chain actors, by improving their internal control systems. In addition, efforts were made towards the unification of these actors and the augmentation of their representativeness at a national level. These led to the execution of workshops aimed at training leaders; the execution of multiple national meetings for producers, processors and sellers; and the execution of several training courses and workshops for producers. Even if the real impacts of those training and unification efforts are unknown, there is no doubt that, at least, after so many years of workshops and meetings, the actors got to know each other better.

The area of ***Legislation, Norms and Procedures Simplification*** focused on providing a legal framework to the producer organizations[22]. In effect, these were facing several legal, commercial and tax problems since they were not formally recognized as economic agents. The idea was to deploy a legal framework which allows the quinoa producer organizations have the same rights as the recognized economic agents. Four years had to pass since the idea was proposed, in order to present, to the National Congress, a project of Law of Communitarian Companies[23], which was not yet approved. The project of Law is aimed at recognizing the producer organizations as formal economic agents so they can: (a) have the right of signing contracts, (b) have a bank account, (c) accede to loans, (d) export, (e) be part of the national tax regime, and (f) invoice their sales.

This last point is of great importance for the clients of the producer organizations (the processing companies). In effect, the processing companies would be able to generate fiscal credit. Actually, the Bolivian tax system allows the accumulation of fiscal credit with the presentation of the invoices of materials purchases. This fiscal credit can then be used to reduce the amount paid for the Value Added Tax. As the quinoa processing companies purchase the raw quinoa without invoice, they can not reduce their amount paid for the Value Added Tax so, in relation to other companies of other sectors, they are in disadvantage. One of the most important production costs of the quinoa processing companies is related to the purchase of raw grain (approximately 70% of the total production costs) [24].

[21] FPS: Fondo de Inversión Pública y Social.
[22] These organizations are called "Organizaciones Económicas Campesinas" (OECAS).
[23] This project of Law was presented to the Bolivian Congress on the 10th of January 2008 by the Superintendency of Companies (Superintendencia de Empresas, in Spanish), an actor that did not exist in 2002, when the subject was proposed.
[24] Calculated from the costs structure of the companies ANAPQUI and JATARY in 2002.

Before presenting the mentioned Project of Law, there was an attempt to implement a mechanism of auto-invoicing for the processing companies. This way, these companies could compensate their disadvantage receiving fiscal credit for their purchases of raw grain. This initiative never materialized. Nevertheless, the proposal of Law of Communitarian Companies, in its Article 19, establishes that the tax system applies to all producer organizations or Communitarian Companies. However, some problems exist in the definition of the tax aliquots, namely, a progressive reduction of all different taxes aliquots, as follows:

a) During the first three years, the taxes aliquots will be reduced by a factor of 10% to 30%
b) Between the 4th and 6th year, by a factor of 30% to 50%.
c) From the 7th year, by a factor of 50% to 100%.

Evidently, from the 7th year on, the tax payment reductions will be of 100%, which would be equivalent to the current situation. Thus the proposal of Law encourages the establishment of Communitarian Companies but will not achieve the integration of these companies into the national tax regime. If the Law is approved, the Communitarian Companies will have an advantage over those companies which carry out the same activity but are not communitarian.

On the other hand, according to the proposal of Law, the Communitarian Companies will be able to use and circulate Taxes Devolution Certificates (CEDEIM[25], in Spanish) which are currently applied to he Bolivian companies that export. With these Certificates, the exporters can get the money paid for the Value Added Tax back. It does not seem fair that other companies which do not have the same obligations can enjoy the same privileges.

The area of ***Foreign Trade, Exports Promotion and Incentives for the local consumption*** was oriented to the accomplishment of three objectives: (a) to reduce the illegal quinoa sales to Peru encouraging legal exports to that country, (b) to promote the grain of quinoa and value added products in international markets, and (c) to promote the internal consumption of quinoa.

In relation to the first objective, one of the problems that the Bolivian quinoa processing companies face is the disloyal competition of the quinoa “rescuers” (national and international) that sell the grain illegally, mainly, to Peru. The competition is disloyal because the Bolivian processing companies support the producers in their supply programs in order to guarantee the raw grain provision. This implies to cover the costs of the lands organic certification, to provide the producers with work equipment, and to train them. In several cases, however, those efforts fail in maintaining solid commercial relations. Some producers prefer to sell the grain to those buyers that offer a higher price, refusing to supply those companies that worked for their progress. This, indeed, weakens the commercial relations between processing companies and producers.

Peru is certainly an attractive market because the internal quinoa consumption is greater than that of Bolivia[26], the prices are higher and the transportation costs from the Peruvian frontier to the Bolivian quinoa production zones are lower because of its proximity. Actually, there are some production zones that, during the rain period, are impossible to reach by road; it is easier to access there from the Peruvian frontier. Moreover, as there is not a proper control at the frontiers, to bring quinoa to Peru without paying taxes results very attractive. For this reason, the Agenda of Shares Responsibility of 2004 defined specific actions aimed at establishing greater controls at the Custom Offices and keeping records of the quinoa quantities leaving the country.
Although there are not exact figures of the quinoa quantities that are sold illegally, the companies of the sector consider that before de technological change, and the subsequent increase in the processing capacity, the amount of quinoa sent illegally to Peru was greater. In effect, even if the agricultural production of quinoa was not enormous, there existed an excess of quinoa that could not be processed due to the reduced capacity of local processing companies. Nowadays, these companies, with their increased processing capacity, compete for buying that excess of quinoa so they have promoted control

[25] CEDEIM: Certificados de Devolución Impositiva
[26] Only in Lima, around 7,000 tons of quinoa per year is demanded.

measures of smuggling at the boundaries with good results. Thus, the reduction of quinoa smuggling has been fundamentally reduced by the augmentation of the local processing capacity. Before the technological change, only 35% of the quinoa agricultural production was processed, at the present time, in contrast, companies can process around 85% of the that production.

As far as the promotion of exports concern, the actions were aimed at financing the participation of the Bolivian companies in different international fairs, executing training courses in exports management and carrying out export market studies. Finally, in order to promote the internal consumption of quinoa, the efforts were focused on including quinoa in specific and concrete segments as the schools breakfast, maternity subsidies, and the food program of the army and the police. There was not an opened and massive campaign aimed at the entire population. Currently, the quinoa consumption is still reduced and limited to the occidental part of the country.

The area of ***Science, Technology and Innovation*** was oriented to promote the coordinated work of various public and private institutions with expertise on the sector and linked to the innovation areas. The respective defined agenda included a regional program of soils and irrigation management, a production system with certified seeds, the recovery of traditional technologies, the development of new sowing technology, fertilization and plagues control, and the development of new harvest and post-harvest technology with an organic focus. To present, the members of the Quinoa Alliance achieved the most important results. They transformed the technological matrix of the quinoa processing, increasing significantly the processing capacity and improving their productivity indicators.

During the time in which the Agenda of Shared Responsibility was established, CPTS had made some progress in the development of processing technology and its commitment was to promote such technology once it was finished. This objective has been accomplished. The new challenge is now focused on the increment of the quinoa agricultural production with the implementation of proper technology.

The area of ***Financing and Loans Access*** pursued the creation of financing mechanisms which offer better capital access conditions to the producers and processing companies. For this, different micro-financing institutions were allocated with resources to execute the correspondent loans. However, these financing mechanisms are not yet suitable for the processing companies and the producers that want to undertake bigger projects. Besides, during the last years, some public institutions and non-governmental organizations intervened, in a disarticulated manner, making donations and granting subsidized credits that discouraged a more active participation of financing institutions.

On the other hand, the most important processing companies of the sector had, as main financiers, their international buyers and not the national financing system. The international buyers allocated resources for the harvesting and transportation of the raw grain at reduced interest rates and without the necessity of following any procedures for obtaining the loan. Indeed, the national financing institutions must re-adjust their products to the necessities of the quinoa sector, a sector that is growing and that will not need a micro-credit any more.

From the productive chains to the productive complex

In 2006, with the new Government, the concept of productive chain was changed to "productive complex". This term adds to the productive chain the territorial dimension. In this new conception, the productive chain must be reffered to a defined territorial space that presents comparative advantages with respect to other regions. The objective is to define the productive vocation of each region and plan its development.

Even if that policy is in not yet well established[27], it is important to take into account that, currently, many quinoa processing and value-added quinoa products companies are not located in producer zones but in cities as La Paz, El Alto, Oruro and Potosí. Thus, the economic dynamic of the sector is not referred to a

[27] In November 2008, a proposal entitled "Perfil Productivo para el Sudoeste de Potosí" will be presented. Southern Potosí is one of the traditional zones of quinoa production in Bolivia.

defined territorial space. In order to integrate the whole value chain into a determined territory, it is necessary to provide them with infrastructure – physic (roads, power lines, gas pipelines, teledensity), social (health and education) and institutional (access to credit and risk management tools). This task demands a great challenge, the coordinated work among the Government, Prefectures and Municipalities.

The lack of capacity of the Government to consolidate a national development plan for the quinoa sector resulted, in many cases, in disarticulated and reductionist actions. Like this, most of the efforts to support the quinoa sector were disarticulated and focused on a small portion of the productive chain. Logically, the impact expected was not accomplished.

In many cases, the disarticulated actions, donations and subsidies aimed at a reduced number of beneficiaries, had little or almost none contribution to solve the fundamental problems. On the contrary, these actions diverted the attention of the decision makers to less important objectives. The donations led to other short-term perverse effects. From the market of financing services point of view, the donations did not incentive a more active action of the financing institutions. From a productive point of view, these paralyzed some producer projects, as false expectations were created about a “gift” that never came.

Evidently, it is easier to invest on punctual or isolated projects, than in comprehensive development projects of long term aimed at bigger and ambitious objectives. At the end, however, there is a risk of losing direction and, to a great extent this was what happened in terms of public policies for the sector.

The project of the Quinoa Alliance is holistic and includes various elements of the intervention plan for the quinoa productive chain. However, two elements differentiate the proposal of the Quinoa Alliance from the proposal of the quinoa productive chain. The first element concerns the definition of a quantifiable productive goal for the sector; the fact of establishing a concrete productive objective allowed the public and private institutions to realize the magnitude of the challenge and re-take actions that had been abandoned.

The second element is related to scientific knowledge. Before, it was knew what had to be done; now, it was known how to do it. The proposal of the quinoa productive chain recognized that the development of the sector needed technological advances, but did not gave the due importance to it. After four years of signing the quinoa ABC, and given the achievements accomplished at the quinoa-processing link, the decision makers now realize the great importance of the technological development. Now, there is a scientific knowledge that allows discerning a different future for the Bolivian Altiplano; a future not based on subsistence agriculture but on sustainable and rentable agro-industry.

7 THE NEXT STEP: AGRICULTURE

The great challenge that the sector is facing now is to achieve a sustainable increase of the agricultural production of quinoa, given that this link constitutes the new bottleneck of the productive chain. The new quinoa-processing technology allows, nowadays, processing almost all the agricultural production. In order to achieve a greater development, the agricultural frontier needs to be expanded in a sustainable manner.

The agricultural production, nowadays, is characterized by the intensive use of labor force with little use of technology. Even if there exists a great extension of communitarian lands for quinoa cultivation, the area exploited is limited to small parcels of land. This is due, fundamentally, to the lack of soils management systems and the absence of proper sowing, harvesting and post-harvesting technology, which hinders the increase of the area of cultivation in sustainable conditions. At present, a quinoa producer can only sow the quantity that the labor force available in the family can harvest. Around the production zone, there is not a market of labor force, the population is scarce and scattered as migration left an extended territory with a population density of 0,5 inhabitants per km^2.

Recent research and trials carried out by CPTS show that the region is feasible; in fact, it can be converted into a development pole for the country. The trails made in field indicate that, with the introduction of proper technology, it is possible not only to increase the crops yield significantly, but also to enlarge the agricultural boundary of the Altiplano in a sustainable manner, using lands that, during decades, were considered to be not suitable for agriculture. In fact, these lands resulted to be the best for quinoa cultivation.

The involuntary contribution of the NASA

During decades, some research was carried out about the quinoa cultivation in the Altiplano. However, only since 2007 the fundamental scientific knowledge on the quinoa cultivation requirements was acquired. The NASA made actually an important contribution through its web page, its 1996 publication entitled “Quinoa: Candidate Crop for NASA's Controlled Ecological Life Support Systems”. This publication oriented the research of CPTS and showed significant contradictions with what was knew about quinoa until then. The study has three main fundamental conclusions:

a. Potassium is one of the most important macronutrients for quinoa (apparently, it is fundamental for quinoa growth, since it is needed for protein and enzyme synthesis and activation, and also for photosynthesis and associated metabolisms; furthermore, it seems to be vital for retaining and maintaining proper water balance under the arid conditions of quinoa growth in Bolivia’s Altiplano).

b. Calcium and magnesium, which are found in high percentages in both, leaves and seeds, must also be considered as vital macronutrients (just like potassium is), due to their function in the plant growth (for instance, magnesium activates several enzymes). However, magnesium, calcium and potassium are found with much higher percentages in leaves and seeds in plants grown under hydrophonic than under field conditions. This means that the lack of availability of these macro nutrients from soils is one of the fundamental factors that diminishes the quality and the yields of quinoa production; and this is an issue that must be addressed using appropriated fertilizers, together with the right amounts of water during the critical stages of plant growth.

c. The photoperiod in Bolivia’s Altiplano, with relatively high instantaneous photon flux levels, is about 8 hours during summer (i.e. during December through March), when most of the plant growth takes place. The high instantaneous flux in the traditional quinoa cultivars is due to the altitude of the Altiplano (i.e. it is over 3,600 meters above sea level) and also to the diffused irradiance created by sunlight reflection from the salt flats (the total area of Uyuni’s salt flats is about 10,000 squared kilometers), which significantly increases the irradiance over the quinoa cultivars located at distances beyond 120 kilometers from the salt flat edges (note that diffused irradiance does not diminishes significantly due to hills interposed between the salt flats and the quinoa cultivars).

The first two conclusions, which are based on the studies for NASA’s CELSS Program, sharply contradict what is currently accepted for quinoa cultivars regarding soil requirements. The following paragraph, translated from a well known FAO technical publication in Spanish[28], is just an example of such contradiction: “*With regard to soil, quinoa prefers … a moderate content of nutrients, since the plant has a high demand for nitrogen and calcium, a moderated demand for phosphorous, and a little demand for potassium”*. This publication contains the results of hundreds of studies on soil (nutrients and pH), water, radiation intensity, clime and temperature carried out in Denmark, England, USA, Chile, Colombia, Bolivia, Peru and Ecuador; and, for incredible that it may appear, scientists have overlooked not only the importance of potassium but also that of magnesium, as well as the nutrient synergies which apparently takes place among some of the macronutrients[29]. Those effects could only be seen under hydrophonic conditions, which allow for unlimited and constant supply of nutrients (this is the best way to establish the equilibrium content of such nutrients within the quinoa tissues and seeds).

[28] QUINUA (*Chenopodium quinoa* Willd.) Ancestral cultivo andino, alimento del presente y futuro. Ed. Angel Mujica S., Sven-Erik Jacobsen, Juan Izquierdo, and Jean Pierre Marathee. Santiago, Chile, 2001; page 23.

[29] Aside from the normal requirement of magnesium to produce chlorophyll, no study for quinoa growth conditions that CPTS is aware of, except that of the NASA study, takes magnesium into account as a vital macronutrient for quinoa.

The ignorance of those technical aspects resulted, during many years, in not applying the correct measures to avoid the soils degradation, in not extending the agricultural extension in adequate conditions, and in not increasing the crops productivity. The sandy and salty latent lands around the salt flats contain large quantities of the quinoa macro nutrients mentioned before (soils are particularly reach in potassium, magnesium and calcium), which are being exhausted over the years since no quick natural replacement takes place. Furthermore, the use of deep plowing techniques contributes to further loss of the macro nutrients due to high velocity winds' erosion. These two factors, combined with the use of harmful pesticides, which eliminates useful soil microorganisms, are significantly degrading the soil productivity currently used for quinoa cultivars.

On the basis of the new knowledge acquired, CPTS developed approximately 16 scientific investigations that not only confirmed the NASA results, but also allowed to look beyond. This way, CPTS designed a methodology to recover the degraded and eroded soils, a methodology to habilitate virgin soils, and a methodology of soils comprehensive management (either recovered or habilitated). As part of these methodologies, CPTS also developed a minimum farming system, an organic fertilizer that makes bio-available all quinoa requirements, an organic and innocuous pesticide for the human being based on saponin and suitable for plagues control, a conic sowing system for the control of parameters that influence the physiologic maturity of the grain, among others. The application of these methodologies in experimental hectares resulted in the increase of the crops yield, the improvement of the grain nutrients content and the optimization of the rate biomass-grain. In addition, the methodologies allow an homogeneous physiologic maturity of the grain, making possible a mechanized harvest, something that was unthinkable years ago.

On the other hand, the research led to one of the most important discoveries: *the sandy and salty soils ("poroma"), abundant in the production zones but, during years, it was thought that this type of soil was not suitable for any food cultivation. In fact, it is best type of soil for quinoa crops*, but no other food can grow in it. At the production zones, there are approximately 4 millions of hectares of this type of soil. The project proposed by the Quinoa Alliance is aimed at habilitating one million of hectares of sandy and salty soils for quinoa cultivation.

The development of the agricultural technology and the model proposed by the Quinoa Alliance

Thanks to the knowledge acquired during the last years of research, CPTS designed and, in cooperation with IMA, built prototypes of farming machinery set, which consist of the following cleaner production farming equipment:

a. Planter. Developed for in situ fertilization and seeding under the minimum farming techniques. This equipment will allow savings from the significantly decreased quantities of fertilizers to be applied in situ, and will significantly reduce soil erosion since no sandy soil plowing will take place.

b. Harvester. Will cut and collect the quinoa shoot ends (panojas) with minimum seed losses; and will cut, mill and collect the stems with their leaves to be mixed latter on with manure to produce compost in order to return significant amounts of nitrogen, phosphorous, magnesium, calcium and potassium to the soil. Furthermore, the harvester will not take the roots out of the ground, in order to stabilize and add structure to the sandy soils.

c. Dryer. Will dry the seeds using heat produced from sunlight, and an air flow created by an ingenious chimney design. This innovation will allow drying physiologically matured seeds in less than 3 days, to get them ready to be threshed, without having the current losses and contamination of seeds with rodent and bird scum, and with stones and rodent and insect fluids, which occurs during the accommodation ("empavillado") and sun-drying of quinoa plants.

d. Thresher and sorter/cleaner. Will innovate the way threshing should take place without hurting the seeds, and without generating unwanted straw, which forms in large quantities due to the current threshing practices (i.e. the entire plants are stepped on and pounded with heavy sticks or passed over with trucks; some producers have threshers adapted from machinery designed for other crops, which are not satisfactory due to economic and efficiency reasons).

On the basis of the new existent technology, the Quinoa Alliance proposes a development model aimed at implementing agricultural productive units equipped with the new technology. These agricultural units can be operated by one or more families, depending on the forms of social organization of production that the communities decide to adopt.

With the designed technology, each productive unit has the capacity of exploiting 250 hectares per year. Therefore, in order to reach the goal proposed by the Quinoa Alliance (1 million hectares of production per year), 4,000 productive units will be required[30]. In addition, each 10 productive units will count with one quinoa processing plant with the same characteristics of those which are already installed. The introduction of the new agricultural technology can represent a huge leap in the productive scale of the quinoa producers as currently, they cultivate from 1 to 3 hectares of quinoa per year.

The achievement of the objective of one million tones per year will result in an outcome, for sales, of 3,000 millions of dollars at the current quinoa prices, or 1,500 millions of dollars assuming that the quinoa price decrease in a half. In either case, the quinoa agricultural sector will become the most important of Bolivia. The Quinoa Alliance believes that this objective can be accomplished. However, more than only technology and investment capacity of the social or private companies will be needed.

The Government must invest in infrastructure – physic (roads, power lines, gas pipelines, teledensity), social (health and education) and institutional (access to credit and risk management tools). Furthermore, it is needed to support and strengthen the productive chain of other sectors that have synergies with the quinoa sector. Finally, the mechanization of the quinoa agricultural activities will require many machinery manufacturers, which must be capable of constructing equipment parts with the needed quality and speed. The challenge is indeed ambitious but it is necessary to consider the whole magnitude of it in order to avoid atomizing efforts and the non accomplishment of the expected impact.

8 CONCLUSIONS

Our analysis reveals that the technological innovation in the quinoa grain processing had a significant impact on the productivity of the Bolivian companies dedicated to this activity, which resulted in a considerable augmentation of the exports and the grew of the sector. This came concurrently with a convergence process of productivity, a consequence of the process mode modification (batch operations were substituted by a continuous process) and introduction of homogeneous protocols of production that are implied with the new technology.

The excellent results led to the natural creation of an alliance among the most important companies of the sector, producer associations and technology manufacturers. The objective of this alliance (the Quinoa Alliance) is to accomplish the quinoa sector sustainable development through the modification of the technological matrix in all the links of the productive chain. The great current challenge is to increase the quinoa agricultural production in a sustainable manner, which is why the research carried out during the last years focused on such an objective. Recent research show that it is possible not only to increase the crops yield significantly, but also to enlarge the agricultural boundary of the Altiplano in a sustainable manner, using lands that, during decades, were considered to be not suitable for agriculture but, paradoxically, for quinoa, they are. The research results were the basis for the design of new agricultural technology specific for the types of soils and ecosystems of the quinoa production regions. It is expected that, the producers, equipped with this technology, will create efficient productive units which allow them to face a process of sustainable growth and development.

[30] Cabe esperar que las unidades productivas sean gestionadas por familias campesinas pertenecientes a una misma comunidad, esto en vista que la tierra que se utilizará es tierra comunitaria, y su uso está restringido a miembros de una misma comunidad.

In order to reach the expected objectives, the technological innovation must come with innovations in the institutions that promote development. The public sector has an important role to play in boosting articulated policies aimed at promoting the adoption of innovations. The generation of technology as well as its adoption is affected by deliberated public policies (e.g. infrastructure development, research funding and activities of agricultural extension), not deliberated policies (e.g. changes of commodity prices), and activities of the private sector. One of the challenges related to the design of development policies based on technological change is an optimal combination of public and private efforts.

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