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Global Trends in the Worldwide Expansion of Quinoa Cultivation †

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Abstract: For centuries, quinoa cultivation was centered only in the Andean countries, and recently it has spread to all regions of the world. Although the number of exporting countries has increased, Bolivia and Peru remain the world's leading producers and exporters. Today, more than 125 countries are experimenting with or cultivating quinoa. The expansion of the crop has only been possible due to the genetic diversity of seeds maintained by generations of farmers in the Andes. As access to quinoa genetic resources in Andean countries remains limited, this implies that the development of new varieties relies on a narrow genetic base relative to the theoretical potential of the species. The use of improved varieties has increased, especially with the emergence of new countries sourcing seed from commercial varieties to start cultivation. To cope with the increasing effects of climate change, it is essential to increase the resilience of crop by taking advantage of their genetic diversity. The current global crisis can only be overcome in the North or in the South by establishing new partnerships for access to genetic resources and the fair and equitable sharing of the benefits of their use. In the last 30 years, quinoa from the Andean countries gained a position in global markets and improved the quality of life of producers. However, at the end of 2015, producer prices collapsed. Quinoa development is dynamic, and now Andean producers face different scenarios with new competitors and new concerns. Being aware of the new reality is essential to face the new challenges responsibly. Analysis at different scales is fundamental, as is promoting local diversity and cooperating towards innovative production systems and inclusive processes that benefit everyone.

Keywords: Andes; biodiversity; cultivation expansion; markets; producers; quinoa

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1. Introduction

Biodiversity conservation today is a key global concern of the international community with the last (IPBES, IPCC, FAO) global assessments in 2019. This loss of biodiversity places our agriculture and our food at risk. In Latin America, the Andean altiplano is one of the centers of origin or "hot-spots" of the world's biodiversity. For thousands of years, the populations have interacted with the agroecosystems. Quinoa crop has evolved from a complex process of biological, geographical, climatic, social and cultural interactions that have determined its current high genetic diversity.

The Pluri-national State of Bolivia has requested the FAO to declare 2013 "International Year of Quinoa (IYQ)". By resolution 66/221 of 22 December 2011, the United Nations General Assembly declared 2013 the International Year of Quinoa (IYQ) and the secretariat was assigned to FAO-RLC (Santiago de Chile). The IYQ aimed to draw global attention to the role of quinoa's biodiversity and nutritional value in food security and poverty eradication in order to achieve the Millennium Development Goals.

Quinoa (*Chenopodium quinoa* Willd.), known as a neglected and underutilized species, was considered a major crop used by the Pre-Colombian cultures in Latin-America for centuries. As a consequence of the invasion and the conquest by the Spanish, cultivation and consumption of this crop were suppressed and thereafter only continued on a minor or local scale. Quinoa has been grown in the Andes for over 7000 years. After centuries of neglect, the potential of quinoa was only rediscovered during the second half of the twentieth century [1]. Following the International Year of Quinoa (IYQ) in 2013, the case of quinoa was highlighted with the potential to rapidly change its status from a minor to a major crop in the world agriculture, on basis of the role that quinoa's biodiversity and its high nutritional value can play in providing global food security [2].

But the question at the heart of global expansion is the following: "Can the nutritional richness of quinoa serve the global food security?". Compared to the major cereals for agriculture and world food (wheat, corn, rice), quinoa has a much higher protein content (from 14 to 19%). But above all, it presents a good balance between all the essential amino acids, with contents above the FAO recommendations for each of them. Much emphasis has been be placed on the quality of quinoa's proteins for its promotion and worldwide recognition, but its nutritional value is more global [3].

The balanced structure of essential amino acids is one of the main characteristics of quinoa, but not the only one. Quinoa grains contain a very high proportion of polyunsaturated fatty acids (especially omegas 3, 6, 9), essential for human growth and development (brain, muscles, retina), as well as very high levels of Vitamin E or tocopherols as powerful antioxidants (α, β, γ and δ) and tocotrienols (α, β, γ and δ) with known biological activity, essential for reproduction and growth of mammals including humans. α-tocopherol in particular is a powerful antioxidant that prevents the oxidation of plant lipids, especially seeds (it also aids in the fight against cholesterol). It protects the body from cell damage and helps maintain a healthy immune system to protect against chronic diseases, such as heart disease and cancer. Quinoa is also very rich in many minerals, and it contains as much fiber as whole grains, useful to moderate the glycemic index of the meal. Vitamin B1 allows the production of energy from carbohydrates (sugars). Vitamin B9 or folic acid (also called folates) is essential for cell renewal and for the development of the fetus during pregnancy.

2. Quinoa Genetic Diversity

The answer to healthy eating lies in the diversity cultivated and maintained by small-scale farmers in the Andes. Quinoa was domesticated near Lake Titicaca between Peru and Bolivia. Generations of farmers have been involved in quinoa selection, which explains the high levels of genetic diversity found today. Quinoa diversity, at a continental scale, has been associated with five main ecotypes: Highlands or Altiplano (Peru and Bolivia), Inter-Andean valleys (Colombia, Ecuador and Peru), Salt flats (Bolivia, Chile and Argentina), Tropical Yungas (Bolivia) and Coastal/Lowlands (Chile). Each of these ecotypes is associated with sub-centres of diversity that comes from the surroundings of Lake Titicaca. And each one corresponds to specific conditions of altitude, latitude and soils and climatic conditions [4–6]. Due to its extraordinary genetic diversity, the crop is highly adaptable to different agroecological conditions and tolerant to frost, drought and salinity [3]. The differences are very pronounced between ecotypes. Each of these ecotypes is associated to specific conditions of altitude, latitude and is adapted to specific soils and climatic conditions. Considering its origin in central and southern Chile, the sea level ecotype appears as the most adapted to temperate and Mediterranean environments. With high attention to the Chilean germplasm, the number of quinoa-producing countries has risen rapidly from 8 (in the 80') until 125 today [7,8].

3. Phases of Quinoa Spreading

From at least 5000 years ago until the beginning of the 1980s, Quinoa has been specific to the Andean countries in South America. But since the other countries understood the potential and benefits of quinoa, the amount of experimentation conducted did not stop growing.

During the 1980s, the multiplication and the spread of experimental stations were directly linked to major international initiatives for research. Research partnerships have often facilitated the exchange of germplasm and have had a powerful impact on this development by strengthened collaborations. However, partnerships between research institutions for germplasm exchanges need to consider legal and ethical aspects related to the access to genetic resources for experimentation and fair commercial development. The first introduction of quinoa in Europe began in 1978, with germplasms coming from Chile (Universidad de Concepción), and then selected and tested in Cambridge, England. From Cambridge, quinoa was distributed to Denmark, The Netherlands and other countries.

The most important project during the 1990s that explains today's quinoa worldwide expansion is the project with the Danish International Development Agency (DANIDA) and the International Potato Center (CIP) in Peru. There were fields trials in new countries, and most of them were involved in the global European and American Test of Quinoa, organized by the FAO (Food and Agriculture Organization of the United Nations). The aim of this project was to create a state-of-the-art quinoa based on multiple experimentations at a global level.

The spread of worldwide quinoa was caused by strong relationships between institutions that shared their genetic material. FAO played a key role on this issue during the International Year of Quinoa.

During the past thirty years, quinoa was tested in all the continents, and nowadays, quinoa is cultivated in more than 125 countries [9]. Quinoa globalization entails challenges to the countries of origin, and these are important to consider for future development. Understanding this reality is fundamental to face the challenges of conserving local biodiversity, developing and promoting new varieties, and cooperating on plant genetic resources exchanges with inclusive processes towards fair benefits with Andean countries [10].

4. The New Quinoa Producers

Who are the new producers of quinoa? Most of them (>90%) are introducing quinoa as a new crop for diversifying their cropping system. And they cultivate less than 2 ha of quinoa and less than 30% of their superficies. Less than 25% of the new superficies are cultivated with irrigation, especially around the Mediterranean sea. We note more organic production in the Andes and conventional production outside. For introducing quinoa, considering the difficulties of accessing quinoa genetic diversity from Andean countries, commercial varieties are mainly used, and new country producers are registering new varieties with Plant Variety Rights (UPOV System) [11].

With the global demand, increasing production in the countries of origin for international market put at risk the agriculture–livestock integration in Andean agroecosystems. But at the same time, from the 1990s to 2008, farmer incomes have been multiplied by 6!; the attractiveness of quinoa has generated new social conflicts over access and land sharing between Andean communities.

There is a strong interest in quinoa in the Mediterranean and in developing countries. It has two main objectives: to help fight malnutrition and to help reduce poverty, because quinoa grains have a high nutritional value and it is a rustic crop than can grow from the sea level to over 4000 m of altitude.

5. Discussion

Today, seed legislations at a global level limits the access to genetic quinoa resources for testing the crop in new environments. Legal restrictions are important for international regulations on seeds and plant genetic resources so that only a very small part of the available genetic diversity is used for the adaptation of quinoa to new environments. Only 3 to 12 local varieties (with high intrinsic diversity) are usually tested simultaneously, and only 1 to 3 certified commercial varieties (Puno, Titicaca) are widely distributed.

First, ***a question of fair access to genetic resources***. Andean countries hold the largest germplasm collections. But many countries have established collections prior to the signing of the Convention on Biological Diversity which specifies that states are sovereign over their genetic material. For quinoa, however, there is no single existing legal framework providing a comprehensive coverage of all the issues related to the genetic resources and their sustainable management. The Convention on Biological Biodiversity (CBD) does regulate bilateral access and benefit sharing, but this is difficult to apply to quinoa as a crop is now planted internationally, not restricted to the Andean region, and this has been the case for decades. This now means that these countries may well develop new varieties from this germplasm without having to refer directly to the country of origin. But one main problem today is the lack of transparency in PGR flows at a global level. Often, the main objective of the trials is not so clear for some countries. There is a need for better defining the objectives of the variety trials [12]. An objective of adaptation from an existing commercial variety differs completely from a strategy of plant breeding for developing new adapted cultivars. Germplasm and experimental design for the trials may be adapted to these two distinct objectives. The Andean peasant varieties of quinoa are heterogeneous and well adapted to extreme climate and soil conditions due to a very high intra-varietal genetic diversity.

Second, ***a question of access to technologies***. Some knowledge and technologies are already available, but there is an imbalance technology access between the North and the South. Key factors for the expansion of the quinoa and future improvement and breeding are the following items: using molecular markers (SSR linkage map, marker-assisted selection), improving feature selection based on genes of interest, PVB/PPB methods, adaptation to climate change and salinity using variability.

Third, *a question of sustainable development*. How can we consider sustainable agriculture development for food security and nutrition with NUS? Quinoa is a good example of an adaptive crop for many environments that can help to restore agricultural systems in marginal and degraded areas, considering its tolerance to salinity and drought. But how can we improve resource efficiency of production, and also of natural resources (soil, biodiversity, water, etc.)? To achieve sustainable development goals, we need to think about agricultural systems resilience against risk, against variability and against uncertainty. At the same time, social aspects also need to be considered, like land access and sharing, seed exchanges, cooperatives and farmers' organization for transforming quinoa and assessing to markets, etc. In addition, new country producers have difficulties introducing quinoa grains in their national markets considering post-harvesting operations. Therefore, training both farmers and agricultural advisors is essential for developing a complete quinoa value chain. Elaborating and testing local dishes with quinoa from the beginning of the programs could be key for the appropriation of the quinoa as a food crop for the population and for its integration into their diet.

6. Conclusions

Drought resistance, salinity tolerance and exceptional nutritional value are some of the advantages of quinoa facing the effects of climate change in agriculture. But access to genetic resources is necessary to allow the adaptation of an exotic species in new environments. Research plays a central role in the development of quinoa through international collaborations. It is necessary, however, to be patient before expecting commercial production. Adoption of quinoa by local populations is essential for producing it in a sustainable way.

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References

1. Bazile, D. *La quínoa. Los Desafíos de una Conquista*; LOM Ediciones: Santiago, Chile, 2016.
2. FAO & CIRAD. *State of the Art Report on Quinoa Around the World in 2013*; Bazile, D., Bertero, H.D., Nieto, C., Eds.; Food and Agriculture Organization of the United Nations (FAO): Santiago, Chile, 2015.
3. Ruiz, K.B.; Biondi, S.; Oses, R.; Acuña-Rodríguez, I.S.; Antognoni, F.; Martinez-Mosqueira, E.A.; Coulibaly, A.; Canahua-Murillo, A.; Pinto, M.; Zurita, A.; et al. Quinoa biodiversity and sustainability for food security under climate change. A review. *Agron. Sustain. Dev.* **2014**, *34*, 349–359. [CrossRef]
4. Fuentes, F.F.; Martinez, E.A.; Hinrichsen, P.V.; Jellen, E.A.; Maughan, P.J. Assessment of genetic diversity patterns in Chilean quinoa (Chenopodium quinoa Willd.) germplasm using multiplex fluorescent microsatellite markers. *Conserv. Genet.* **2009**, *10*, 369–377. [CrossRef]
5. Fuentes, F.F.; Bazile, D.; Bhargava, A.; Martinez, E.A. Implications of farmers' seed exchanges for on-farm conservation of quinoa, as revealed by its genetic diversity in Chile. *J. Agric. Sci.* **2012**, *150*, 702–716. [CrossRef]
6. Bazile, D.; Fuentes, F.; Mujica, A. Historical perspectives and domestication. In *Quinoa: Botany, Production and Uses*; Bhargava, A., Srivastava, S., Eds.; CABI Publisher: Wallingford, UK, 2013; pp. 16–35.
7. Bertero, H.D.; De la Vega, A.J.; Correa, G.; Jacobsen, S.E.; Mujica, A. Genotype and genotype-by-environment interaction effects for grain yield and grain size of quinoa (Chenopodium quinoa Willd.) as revealed by pattern analysis of international multi-environment trials. *Field Crops Res.* **2004**, *89*, 299–318. [CrossRef]
8. Christensen, S.A.; Pratt, D.B.; Pratt, C.; Nelson, P.T.; Stevens, M.R.; Jellen, E.N.; Coleman, C.E.; Fairbanks, D.J.; Bonifacio, A.; Maughan, P.J. Assessment of genetic diversity in the USDA and CIP-FAO international nursery collections of quinoa (*Chenopodium quinoa* Willd.) using microsatellite markers. *Plant Genet. Resour.* **2007**, *5*, 82–95. [CrossRef]
9. Alandia, G.; Rodriguez, J.P.; Jacobsen, S.E.; Bazile, D.; Condori, B. Global expansion of quinoa and challenges for the Andean region. *Glob. Food Sec.* **2020**, *26*, 100429. [CrossRef]
10. Andreotti, F.; Bazile, D.; Biaggi, M.C.; Callo-Concha, D.; Jacquet, J.; Jemal, O.M.; King, O.I.; Mbosso, C.; Padulosi, S.; Speelman, E.N.; et al. When neglected species gain global interest: Lessons learned from quinoa's boom and bust for teff and minor millet. *Glob. Food Sec.* **2022**, *32*, 100613. [CrossRef]
11. Bazile, D.; Jacobsen, S.E.; Verniau, A. The global expansion of quinoa: Trends and limits. *Front. Plant Sci.* **2016**, *7*, 622. [CrossRef] [PubMed]
12. Bazile, D.; Pulvento, C.; Verniau, A.; Al-Nusairi, M.; Ba, D.; Breidy, J.; Hassan, L.; Maarouf, I.M.; Mambetov, O.; Otambekova, M.; et al. Worldwide evaluations of quinoa: Preliminary results from post international year of quinoa FAO projects in nine countries. *Front. Plant Sci.* **2016**, *7*, 850. [CrossRef] [PubMed]