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RESEARCH PAPER

Improvement of Quinoa (*Chenopodium quinoa* Willd.) and Qañawa (*Chenopodium pallidicaule* Aellen) in the context of climate change in the high Andes

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Abstract

A. Bonifacio. Improvement of Quinoa (*Chenopodium quinoa* Willd.) and Qañawa (*Chenopodium pallidicaule* Aellen) in the context of climate change in the high Andes. Cien. Inv. Agr. 46(2): 113-124. Quinoa and qañawa are the only native crops that produce food grain in the high Andes. The improvement of quinoa has been addressed by government institutions, universities and NGOs, obtaining improved varieties. However, qañawa has received little or no attention in the development of varieties, and only native varieties and revalued varieties exist. The native and improved varieties of quinoa have contributed to food production for rural families and for export, generating significant economic income. In recent decades, the production of these grains has been negatively affected by the effects of climate change. In the high Andes, climatic variability, together with climate change, disturbs the regime of climatic factors, with evident changes represented by drought, frost, hail and wind. The objective of this paper is to describe the context of climate change, review the progress in the improvement of quinoa and qañawa and propose adjustments to improve production methods in the high Andes. The genetic methods and materials used in the improvement of quinoa have allowed varieties with prioritized characters to be obtained in the last decades, and these varieties have met and continue to fulfill their roles in food production and income generation for producers. However, in the face of the effects of climate change, some varieties are becoming unfit for production, especially those with long growth cycles. Therefore, it has been proposed that new breeding objectives, new genetic materials for improvement and new sources of characters are needed, and production improvement methods in the context of climate change are suggested.

Keywords: Climate change, crop improvement, qañawa, quinoa

Introduction

The Andes is an area where crops that produce grains, tubers and food roots have been domesticated and developed for the inhabitants of this area. In the high part of the Andes (high Andes), between 3800 and 4500 m.s.l, the main grain crops produced are quinoa and qañawa. These crops were domesticated, conserved and used by men and women of predecessor civilizations, such as the Tiahauancota and Incaica. Subsequently, contemporary generations have taken advantage of these genetic resources.

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Until the 1980s, quinoa and qañawa were produced for the subsistence of rural families and for local markets. Since the 1990s, thanks to the discovery of its outstanding nutritional properties and the promotion of its consumption, quinoa has entered the national and export markets, reaching the highest demand between 2013 and 2014. According to Montero and Romero (2017), in 1998, the world production of quinoa was 49,400 t, of which 20,921 t were produced in Bolivia and 28,171 t in Peru; for 2016, world production reached 148,720 t, of which Bolivia produced 65,548 t, and Peru produced 79,269 t. The reports show an increase of 200% in quinoa production over a period of 15 years.

The demand for quinoa in the market has led to increased production mainly based on the expansion of the area under cultivation, causing some areas to become monocultures of quinoa, with negative consequences for sustainable production (Risi *et al.*, 2015).

Qañawa has not met the same demand in the market. Therefore, production has continued on a smaller scale, although there is some increase in the acceptance of the product in the local and export markets.

As the international market for quinoa increased, the consequences of climate change became more evident, with adverse effects on quinoa and qañawa production. According to Risi *et al.* (2015), the yields of quinoa have decreased, which they attributed to monoculture and low soil fertility. However, it is very likely that factors associated with climate change contributed to the decline in yield.

Various concepts of climate change have been raised. According to Useros (2013), there are two generally accepted concepts, "that of the IPCC and that of the UN Framework Convention. The first focuses on the identifiable change in climate, regardless of whether it is due to natural variability or results from human activity, and the second refers to the change induced by human activity, whether directly or indirectly, and that adds to the natural climatic variability".

The adverse climatic phenomena in the high Andes are drought, frost, hail and wind. These adverse factors affect quinoa and qañawa, but the effects are differentiated for species and within varieties of the same species.

In this context, the genetic improvement of quinoa and qañawa must play an important role in obtaining varieties adapted to the new context of climate change while satisfying the quality requirements for the product in the local and export markets.

Based on the described background, the present work provides a brief description of the context and a review of the advances in the improvement of quinoa and qañawa in the high Andes, including the methods used and varieties generated to date. Then, we propose some adjustments in the methods of improvement of quinoa and qañawa in the context of climate change.

The adverse effects of climate change in the high Andes

The agriculture of the high Andes has always been developed in an environment of climatic variability. The phenomena of drought and frost have been present in a range of variation that the farmers have managed based on local technologies and management of agroecosystems. However, with the effects of climate change, the varietal component requires adjustments so that the production of quinoa and qañawa can adapt to climate change.

In much of South America, the episodes of El Niño and La Niña affect the temporal and spatial distributions of rain, with episodes of El Niño causing below-normal rainfall and La Niña episodes causing higher-than-normal rainfall (Herzog *et al.*, 2012 and Vuille, 2013).

According to projections, until the middle of the 21st century or until the end of the century, in the high plains and the subtropical Andes, the tendency will be to decrease precipitation by up to 10%, with evidence of severe impacts of the climatic extremes that are occurring or that may occur in the region (Herzog *et al.*, 2012).

In the Bolivian highlands, the adverse factors related to climate change are drought, frost, hail, and wind. These factors negatively affect the production of crops at different stages of their development.

Drought

In the highlands, drought occurs at the beginning and at the end of the rainy season (García *et al.*, 2015). In the rain fed agriculture system, drought may occur at sowing time, in the stage of vegetative development and in the reproductive phase of quinoa and qañawa.

Drought in the sowing season leads to postponed sowing. If it causes failures in the emergence of seedlings, it leads to repeated or canceled sowing. When it occurs in the vegetative phase, drought causes growth retardation, with the consequent lengthening of the productive cycle; while in the reproductive phase, drought accelerates maturation. Quinoa has an outstanding capacity for adaptation to drought and other adverse conditions; thus, it has valuable potential for overcoming the future challenges of climate change (Zurita-Silva *et al.*, 2014).

In relative terms, quinoa tolerates drought better than qañawa; however, the precocity of qañawa and the low sensitivity to photoperiod allows qañawa to reach its productive cycle even if the planting date is delayed.

Frost

In general, when frost occurs on fields with quinoa and qañawa cultivation, quinoa is more affected than qañawa. Qañawa is a frost-tolerant species and can provide high yields in marginal soil conditions (Rojas *et al.*, 2010). On the other hand, in both crops, the sensitivity to frost differs according to the phenological phase of the plant at the time of frost occurrence. In the seedling phase, both quinoa and qañawa are highly tolerant to frost, and susceptibility increases as their development proceeds, becoming more sensitive in the flowering stage.

In quinoa, frost damage causes freezing of the leaf tissue, showing immediate and visible effects. However, the frost also causes the death of the epidermal tissue of the stem, and this damage becomes evident in stages subsequent to the occurrence of frost. These damages are considered as the consequences of the frost since they are observed after the occurrence of frost. These consequences are longitudinal cracking of the stem, superficial necrosis of the stem tissue and finally, the fall of the plants.

According to Jacobsen *et al.* (2007), quinoa possesses the capacity for overcooling, which prevents damage by avoiding ice formation by means of moderate overcooling; in addition, they report that quinoa has high levels of sugar that could reduce the freezing point.

Hail

The damages caused by hail in the crops are determined by the characteristics of the hail, such as the size, amount of hail that falls per unit of area and the strength of the winds during the occurrence of hail (Bal *et al.*, 2014).

Crop resistance to hail depends on the physiological state of the plants and soil moisture conditions, since plants that grow with good moisture have greater elasticity and increased resistance to hail (Sanchez *et al.*, 1996).

According to the local knowledge of farmers in the highlands, for decades, hail has occurred in well-located areas and for a very short period of time. The occurrence of hail was likely at the beginning and at the end of the rainy season. However, in recent years, hail is likely to occur throughout the rainy season, causing serious damage to crops since in that period, the plants are in the developmental phase.

The damage caused by hail varies according to the growth stages of quinoa. The most sensitive stages are the flowering stage and the beginning of grain filling or maturation (García *et al.*, 2015). At sowing, the hail causes soil compaction, preventing seedling emergence. In the juvenile plant stage, hail causes breakage of leaves and stems. In the flowering phase, hail leads to floral abortion, and in the mature state, hail causes the grain to fall.

Hail has an impact on the quinoa plant. The punctual lesions caused by the hail blows become necrotic over time and develop fungal infection sites. The injured and necrotic stem sectors become fragile and break when the wind blows, causing those plants to fall.

Hail tolerance varies with variety (García *et al.*, 2015). However, there are few records of the characterization of quinoa germplasm to the tolerance of hail damage.

Wind

The wind is another factor whose occurrence has increased in frequency and speed. Until approximately 30 years ago, the wind had a well-defined seasonal occurrence. In the Bolivian highlands, the month of August is known as the month of winds, and the wind speed in the past was not as erosive. Currently, the occurrence of wind has been extended to the sowing season, plant growth season and even harvest time. The adverse consequences of wind are more damaging in fields with sandy soils.

In the cotyledonal phases up to the development of two opposite leaves, the seedlings are buried by the sand carried by the wind. In the vegetative stage, the sand transported by the wind causes injuries to the leaves and stems due to sand abrasion. In mature (dry) plants, the wind causes the grain to fall due to friction between plants shaken by the wind. In the drying and threshing stage, the wind transports the harvested material, causing shattering and mixing the grain with sand.

Advances in the improvement of quinoa and qañawa

Improvement of quinoa

The improvement of quinoa in the Andean highlands began in the 1960s and 1970s when methods of mass selection, individual selection, panicle-furrow selection, pedigree selection and the backcross method were proposed (Gandarillas cited by Bonifacio *et al.* (2014 a). Subsequently, Bonifacio *et al.* (2014 b) included other methods, such as stratified mass selection, combined individual-mass selection, single seed descent and the massive method. At that time, the objectives of improvement were the yield, large grain and free of saponin (Bonifacio *et al.*, 2014 and Gómez-Pando, 2015). Since the 1990s, efforts have been made to obtain early maturing and mildew disease-resistant varieties (Bonifacio *et al.*, 2014a, Bonifacio *et al.*, 2014b). Since 2000, hail tolerance has been considered a selection criterion in quinoa. Gomez-Pando and Aguilar (2016) indicate tolerance to adverse climatic factors such as frost, drought and hail among the selection criteria in quinoa for the highlands.

Initially, artificial hybridization was the method for the combination characters and for the segregation of characters in the process of quinoa improvement (Bonifacio *et al.*, 2014, Gomez-Pando, 2015). Subsequently, an induced mutation technique to generate variation in quinoa was suggested (Gomez-Pando and Eguiluz de la Barra, 2013, Bonifacio *et al.*, 2014, Gomez-Pando, 2015). On the other hand, the participatory evaluation of genetic materials has been adopted in a scheme of prebreeding and direct use of germplasm (Rojas *et al.,* 2010).

The domestication of the plants has been carried out since prehistory and with very long processes, where the first domesticated forms were cultivated together with their wild relatives, facilitating a genetic flow to maintain the genetic diversity (Prohens *et al*., 2017).

With advances in molecular biology, modern tools have recently been developed for the molecular characterization of genetic diversity and for molecular marker-assisted selection (Mason *et al*., 2005, Jarvis *et al*., 2008).

Yasui *et al.* (2016) worked to obtain a pure line of quinoa (Kd) that allowed them to perform a rigorous molecular analysis, and they assembled the genome sequence of the Kd line, which provided an important basis for determining the precise roles and numbers of candidate genes and pathways that regulate tolerance to abiotic stress in quinoa. On the other hand, Jarvis *et al.* (2017) assembled the reference genome sequence for quinoa, and this sequence allowed them to identify the transcription factor that most likely controls saponin production in quinoa seeds and a mutation in lines of sweet quinoa, stating that these advances in developing modern tools are the first step to accelerate the improvement of quinoa.

The application of these methods of improving quinoa in the programs of Bolivia and Peru has allowed improved varieties to be obtained. Tables 1, 2, 3 and 4 show the list of quinoa varieties from Peru and Bolivia for highland conditions.

The improved varieties of quinoa in Peru are sweet, semisweet and small to large in seed size (Table 1). The productive cycle of early varieties is in the range of 140 to 150 days, while the late cycle is 190 days. From the above, it can be deduced that the long-cycle varieties are unsuitable for the effects of climate change.

The varieties obtained by the program of improvement of the former IBTA have sweet, medium sized grain (Table 2), coinciding with the objectives of the improvement, which was to encourage local consumption. On the other hand, it is observed that the improved varieties are adapted to the Central Highlands of Bolivia with a precocious production cycle in relation to Peruvian varieties.

In recent years, the genetic improvement of quinoa in Bolivia has had greater emphasis on precocity, maintaining large grain size with and without the presence of saponin (Table 3). It could be said that the varieties of Bolivia have greater options of adaptation to the conditions imposed by climate change due to their characteristics for avoidance of the adverse climate factors.

According to Bonifacio *et al.* (2014a) and Bonifacio *et al.* (2014b), most of the varieties recently released in Bolivia have a short growing cycle,

Table 1. Quinoa varieties selected for the Peruvian altiplano.

Variety	Saponin	Grain color	Grain size	Days to maturity	Adaptation
INIA 431 Altiplano	Sweet	Cream	Large	---	Altiplano, Costal
INIA 420 - Negra Collana	Sweet	Gray	Small	136 a 140	Altiplano, Valley, Costal
INIA 415 – Pasankalla	Sweet	Gray	Medium	140	Altiplano Valley Costal
Illpa INIA	Sweet	Cream	Large	150	Altiplano
Salcedo INIA	Sweet	Cream	Large	160	Altiplano, Valley Costal
Blanca de Juli	Sweet	Cream	Small	160 a 170	Altiplano
Cheweca	Semi sweet	Cream	Medium	180 a 190	Altiplano
Kankolla	Semi sweet	Cream	Average	160-180	Altiplano
Rosada Taraco	Biter	Cream	Small	---	Altiplano
Tahauaco	Semi sweet	White	---	170 a 190	Altiplano

Source: Prepared based on Apaza *et al*., 2013; Gomez-Pando and Aguilar, 2016.

Table 2. Quinoa improved varieties released by the former IBTA in Bolivia (1967–1996).

Variety	Saponin	Grain color	Seed size	Days to maturity	Adaptation
Sajama	Sweet	White	Medium	150	Central altiplano
Samaranti	Sweet	White	Medium	160	Central altiplano
Huaranga	Sweet	White	Medium	160	Central altiplano
Chucapaca	Sweet	White	Medium	160	Central altiplano
Kamiri	Sweet	White	Medium	140	Central altiplano
Sayaña	Sweet	Yellow	Medium	145	Central altiplano
Ratuqui	Sweet	White	Medium	140	Central altiplano
Robura	Sweet	White	Medium	170	Central altiplano
Jiskitu	Sweet	White	Medium	140	Central altiplano
Amilda	Sweet	White	Medium	160	Central altiplano
Santa María	Sweet	White	Large	170	Central altiplano
Intinayra	Sweet	White	Large	160	Central altiplano
Surumi	Sweet	White	Medium	160	Central altiplano
Jilata	Sweet	White	Large	170	Central altiplano
Jumataki	Sweet	White	Large	160	Central altiplano
Patacamaya	Sweet	White	Large	145	Central altiplano

Source: Prepared based on Risi, Rojas y Pacheco (2010).

Table 3. Varieties obtained by the PROINPA Foundation (1999 -2010).

Variety	Saponin	Seed size	Grain color	Days to maturity	Adaptation
Jach'a Grano	Bitter	White	Large	145	Altiplano Central y norte.
Kurmi	Sweet	White	Large	160	Altiplano Central y norte
Aynuqa	Sweet	White	Large	145	Altiplano Central
Horizontes	Bitter	White	Large	145	Altiplano Sur y Central
Qosuña	Sweet	White	Large	150	Altiplano Sur y Central
Blanquita	Sweet	White	Medium	160 to 170	Altiplano Norte, Valles

Prepared based on Bonifacio and Vargas (2005), and Risi, Rojas y Pacheco (2015).

are resistant to mildew (Jacha Grano, Kurmi and Blanquita) and are tolerant to hail (Blanquita). These varieties have greater options to adapt to the conditions generated by climate change. However, it is advisable to have a greater diversity of varieties with these characteristics.

Real quinoa is composed of 54 native varieties or ecotypes, of which at least 12 are the most important (Bonifacio *et al.*, 2012). All the varieties are large seeded and bitter (Table 4). Real quinoa includes early and semi-precocious varieties, so its options for adapting to climate change are high. It is assumed that it was obtained by the method of mass selection and that the conservation of the variety was through varietal purification by the producers.

According to Apaza *et al.* (2013), quinoa is very versatile and adaptable to different ecological environments and can grow in desert climates, even in hot and dry weather, as it can also withstand temperatures from -8 °C to 38 °C due to the diversity and genetic variability.

Improvement of qañawa

Qañawa is a relegated crop even in its own center of origin, and its distribution outside the high Andes is unknown. Qañawa belongs to the group of so-called forgotten and underutilized crops (Rojas *et al.*, 2010). The cultivation of qañawa occurs exclusively in rural communities located at high altitudes in Bolivia and Peru (3800 to 4500 masl).

The production of qañawa is on a smaller scale due to a series of technological, biophysical and social limiting factors. However, it has some advantages that can be used in production and consumption. According to Woods and Eizaguirre (2004), qañawa has an advantage over quinoa, since its seed contains low saponin, making it faster and cheaper to obtain edible flour from qañawa, while in quinoa, removing saponin is expensive.

Researchers of Andean crops agree in qualifying the qañawa as a semidomesticated species due to the small size of the plant, branched habit and dehiscent grain before and during the harvest. These characteristics of the plant are coincident with the wild complex. Despite the knowledge of the factors that limit the increase in qañawa production, the process of genetic improvement has not been implemented to overcome the wild-type characters.

Qañawa plants have very small flowers (1.5 mm), making artificial crossing difficult. Therefore, the methods of improvement are limited to mass selection and individual selection (Apaza, 2010). According to Apaza (2010), the improvement of qañawa is focused on obtaining greater yields and achieving uniformity in seed maturation.

Bonifacio (2018) proposed adjusted methods for qañawa improvement, including mass selection, individual selection, plant-furrow selection, massive conduction of descendants and the adjusted single seed descent method.

The improvement of qañawa was concentrated on evaluating the yield performance of materials conserved in germplasm banks (Pinto *et al.*, 2008). This means there was direct use of germplasm genetic material, using the method of mass selection to revalue germplasm accessions. Paucara (2016) and Bonifacio (2017) reported the results of evaluating mutant qañawa lines whose grain yield and lower preharvest shattering were encouraging for obtaining new varieties.

Table 4. Principal native varieties of Quinoa Real (Bolivia).

Variety	Saponin	Seed color	Seed size	Days to maturity	Adaptation
Real Blanca	Bitter	Large	White	170	Southern and Central altiplano
Pandela	Bitter	Large		175	Southern and Central altiplano
Toledo	Bitter	Large	Orange	173	Southern altiplano
Otusaya	Bitter	Large	White	165	Southern altiplano
Qanchis Blanco	Bitter	Large	White	145	Southern altiplano
Maniqueña	Bitter	Large	White	143	Southern and Central altiplano
Pisanqalla	Bitter	Large	Brown/red	170	Southern altiplano
Ch'aku	Bitter	Large	White	172	Southern altiplano
Q'illu	Bitter	Large	Amarillo	172	Southern altiplano
Rosa Blanca	Bitter	Large	White	178	Southern altiplano
Achachino	Bitter	Large	White	176	Southern altiplano
Ch'ullpi	Bitter	Large	Cream/	156	Southern altiplano

Source: Prepared based on Bonifacio *et al.*, 2012.

Table 5. Characteristics of qañawa varieties in Bolivia.

Variedad	Tipo	Days to maturity	Plant colo	Grain color	Commercial yield kg ha^{-1}	Potencial yield kg ha^{-1}
Illimani	Last'a	160	Pink/Orange	White/gray	800 kg ha^{-1}	2000
Kullaca	Last'a	140	Purple	White/gray	700 kg ha^{-1}	1200
Condornayra	Last'a		Red	Red		1350
Warikunka	Saiwa		Beige	Brown		2250
Ak'apuya	Last'a		Purple	Orange		1600
Pukaya	Saiwa		Orange	Brown		1950
Kullpara	Last'a		Pink	Gray		1200
UMSA 2006	Last'a		Yellow	Gray		1650
AGRO 2006	Last'a		Yellow	Gray		1250

Source: Prepared based on Pinto *et al.*, 2008, and Pinto *et al.*, S.f., Giménez *et al.*, 2017.

The list of improved varieties in Bolivia is presented in Table 5, which are scarcely disseminated, so it is cultivated on a smaller scale.

In addition to the varieties detailed in Table 5, in the municipality of Toledo, Oruro, three new varieties have been selected: Janco, Samiri and Wila, which have characteristics of tolerance to drought and frost.

The varieties selected in Peru are Cupi, Ramis and Illpa INIA-406, and a series of multilinear varieties are in the process of being formed (Apaza, 2010).

On the other hand, in Bolivia, there are native varieties such as Last'a, Saiwa or Chilliwa, Wila, Q'illu, and Ch'uxña, among others (Bonifacio, 2018). In Peru, the local varieties are Akcallapi, Chilliwa, Konacota, Lambrana, Pantila, Kello, Condor saya, Chusilla, Pacco chilliwa, Kello huitil, Chusilla, Paco chiliwa, and Huanacuri, among others (Tapia & Fries, 2007). These varieties generally have a productive cycle between 130 and 200 days.

Methods of improving quinoa and qañawa for the context of climate change

Under climate change, the working scenario for plant improvement include high temperatures, high CO2 concentration, higher frequency of drought, increase in areas affected by salinity and higher frequency of biotic stress, where conventional breeding and biotechnology can help by developing new varieties that can adapt to stress (Ciccareli, 2008).

In the highlands of Bolivia, climatic variability, together with climate change, has had disturbing effects on environmental factors, with changes in the regime of climate factors becoming more evident. To this end, the anthropic effects of the expansion of the agricultural frontier of cash crops are added. Therefore, it is necessary to introduce some adjustments in the approach to the genetic improvement of quinoa and qañawa to contribute to adaptation in the context of climate change. The genetic improvement approach must change because the environmental conditions have changed. It is reasonable to assume that crops domesticated 7000 years ago are becoming unsuitable in current conditions, which implies a strong need to work toward improvement.

The objectives of genetic improvement should be properly prioritized to develop varieties superior to those already existing, which may include performance, adaptation, resistance to stress and quality; among these, abiotic stress is the biggest factor limiting productivity, making the search for resistance to abiotic factors the highest priority (García *et al.*, 2018).

Quinoa

The varieties of quinoa in the context of variability and climate change in the high Andes should include the characteristics of precocity, resistance to drought and tolerance to frost and hail. For this, the use of the genetic diversity present in local varieties as well as the application of conventional and modern breeding tools should be considered.

In the resistance to drought, it is necessary to identify the mechanisms involved, such as escape or tolerance. Escape from drought tends to minimize the interaction of this factor with the growth of the crop and its yield, while tolerance provides a productive capacity despite the loss of moisture from the plant (García *et al.*, 2018).

For precocity and escape from drought, current varieties of the shortest growing cycle should be chosen, crossing these progenitors and favoring segregation in the F2 and subsequent generations which allows the accumulation of favorable genes for superior precocity. The selection methods suggested in order of priority are the mass method, single seed descent, pedigree selection, individual selection and mass selection. Preliminary observations lead to the assumption that quinoa growing under stress conditions undergoes epigenetic changes that lead to natural segregation, as observed in the Real Pandela variety and in others.

For precocity, it is important to consider wild relatives known as ajara (*Chenopodium quinoa var melanospermum*). The suggested method for incorporating the genes of precocity is backcrossing. The domestication of the plants has been carried out since prehistory and with very long processes, where the first domesticated forms were cultivated together with their wild relatives, facilitating a genetic flow to maintain the genetic diversity (Prohens *et al*., 2017).

An ambitious objective is the perennialization of quinoa, allowing consecutive harvests with the least degree of soil disturbance. In Bolivia, wild quinoa with a multiyear growing cycle is being multiplied. The suggested method to incorporate this character into quinoa is backcrossing by the introgressiomics approach (Prohens *et al*., 2017).

Another option to address the improvement in the context of climate change is the cultivation of wild relatives and implementation of selection plans in the ajara, as well as crossing with these genotypes, followed by selection for precocity and resistance to drought.

The sources for hail tolerance are found in the local varieties of the Central and Northern Highlands. Obtaining a variety with tolerance to hail (Blanquita) is encouraging to continue in the search for tolerance to hail. Therefore, improvement in hail tolerance should begin with the evaluation of the genetic material of the germplasm bank.

For the tolerance of quinoa to abrasion by sand carried by the wind, there are no promising materials identified, but it is assumed that the genetic sources may be found in the ecotypes of the Southern highlands. Local varieties are those that have evolved during decades under particular environmental conditions, so they are well adapted to that context and are capable of absorbing the usual environmental variations of the area (Ruiz de Galarreta *et al.,* 2016).

Qañawa

The characteristics of interest for selection in qañawa are the precocity and less grain dehiscence. The last character is a priority since the dehiscence of the grain is magnified with the occurrence of hail and wind, and this constitutes the main cause of yield loss.

High precocity is found in the wild relative of qañawa. Preliminary evaluations reported maturation between 75 and 100 days. The difficulty of conducting artificial hybridization prevents the combination of characters for precocity from the wild species. Given this, induced mutation is the appropriate method to generate variation and then implement selection in segregating progenies. The applicable methods are the selection by single seed descent and the massive conduction of segregants.

The selection of mutant qañawa lines with the lowest degree of shattering by hail was reported by Paucara (2016) and Bonifacio (2017). The reduced grain dehiscence is attributed to the deformation of inter glomerular leaves that embrace the group of flowers, which decreases the fall of mature grain. The deformation of the leaf blade and the petiole is a mutant character.

Another option is selection in ethno-varieties or landraces and accessions of the germplasm bank. The selection methods available are mass selection, stratified mass selection, individual selection and combined individual-mass selection.

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Resumen

A. Bonifacio. **Mejoramiento de la quinua (*Chenopodium quinoa* Wild.) y qañawa (*Chenopdium pallidicaule* Aellen) en un contexto de cambio climático en los Andes altos. Cien. Inv. Agr. 46(2): 113-124.** La quinua y la qañawa son los únicos cultivos nativos que produce grano alimentico en los Andes altos. El mejoramiento de la quinua ha sido abordado por instituciones gubernamentales, universidades y ONG, obteniendo variedades seleccionadas y mejoradas. Sin embargo, la qañawa ha recibido escasa o ninguna atención en el desarrollo de variedades y solamente se cuenta con variedades nativas y variedades revaloradas. Las variedades nativas y las mejoradas de quinua han contribuido a la producción de alimentos para las familias rurales y también la exportación del grano generando ingresos económicos importantes. En las últimas décadas, la producción de estos granos están siendo afectados negativamente por los efectos del cambio climático. En los Andes altos, la variabilidad climática junto al cambio climático, está perturbando el régimen de los factores climáticos con cambios evidentes que se expresan con sequía, helada, granizo y viento. El objetivo del presente trabajo es la descripción del contexto provocado por el cambio climático, seguido de una revisión de los avances en tema de mejoramiento de la quinua y qañawa y luego proponer algunos ajustes a los objetivos y métodos de mejoramiento para la zona de los Andes altos. Los métodos y materiales genéticos empleados en el mejoramiento de la quinua han permitido obtener variedades con caracteres priorizados en aquel momento, las mismas que cumplieron y siguen cumpliendo su rol en la producción de alimentos y generación de ingresos económicos para los productores. Sin embargo, ante los efectos del cambio climático, algunas variedades están resultando desadaptadas, especialmente aquellas de ciclo largo. Por lo que se ha propuesto incluir nuevos objetivos del mejoramiento así como nuevos materiales genéticos para el mejoramiento, nuevas fuentes de caracteres y sugiriendo algunos métodos de mejoramiento en el contexto de cambio climático.

Palabras clave: Cambio climático, mejoramiento de cultivos, qañawa, quinua

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