Review Article

Quinoa (*Chenopodium quinoa* Willd) production in the Andean Region: Challenges and potentials

SUMMARY

Quinoa (*Chenopodium quinoa* Willd) has functional and nutritional value due to its content of amino acids, antioxidants, vitamins, carbohydrates, starch and oil. It is a crop with a wide geographic distribution in the Andean Region, where the greatest diversity of crop forms, genotypes and wild progenitors is found. It is a short day's photoperiod plant, with efficient use of water, photosynthesis and stomatal conductance. It prefers loam-sandy to clay loam well drained soils, because it is sensitive to excess moisture. It requires from 10 to 18 °C with a thermal oscillation of 5 to 7 °C. In Ecuador, quinoa grows between 2500 to 3600 masl; however, in Peru and Bolivia quinoa grows from sea level to 4000 masl. The luminosity of 5 to 7 h day^{-1} is suitable to meet transpiration and photosynthetic processes. Quinoa is the only crop that possesses all the essential amino acids, trace elements, vitamins and does not contain gluten. Regarding fertilization, quinoa is highly demanding of N, P, K and Ca. The production volume of quinoa in the Andes is approximately of 180000 Mg y^{-1} and uses around 191000 ha, with Peru (the leading world producer) reaching the highest production (105000 Mg, 69000 ha), followed by Bolivia (75000 Mg, 121000 ha) and Ecuador (12000 Mg, 7000 ha). The demand of quinoa has increases in USA (60%) and Europe (90%), but those areas have not the agronomic conditions for quinoa´s growth. This opens an international market opportunity for Andean countries. Nevertheless, quinoa´s production faces several challenges.

Key words: Fertilization, International demand, Quinoa production, Weather.

ORIGIN AND DISTRIBUTION

Quinoa (*Chenopodium quinoa* Willd) is a crop with a wide range of geographical distribution, but more specific to the Andean Region in South America, where the greatest diversity of cultivars, varieties, genotypes and wild progenitors is found (Garcia et al., 2015), with the center of origin considered to be in Bolivia. However, over time quinoa has spread to several countries, but remains as an important crop in Bolivia, Ecuador and Peru. It is also known as the *golden grain of the Andes* due to its excellent characteristics for cultivation and nutritional value. In recent times, the increase in production of quality food to feed the world's population needs is a challenge, and quinoa is an alternative for those countries that suffer from food insecurity, especially due to climate change conditions, such as those in the Andean Region (Fig. 1).

Quinoa has been cultivated for around 5000 years, especially in the Andes of Bolivia, Peru, Argentina, Chile, Colombia and Ecuador (Gómez, 2015; Moses and Guwela, 2015). Due to its advantages for cultivation as well as for its adaptation to the diversity of climates and soils (Bhargava et al., 2016), it has spread to other countries in America and Europe, including France, England, Sweden, Denmark, Netherlands and Italy (Jacobsen, 2014); and it is also getting interest in Kenya, India and USA (FAO, 2013). Due to its photoperiod adaptation, selecting the appropriate variety is important for obtaining a good production of quinoa, as varieties adapted to the tropic climate are more sensitive to photoperiod than those adapted to the cold weather of the Andes (Gómez-Pando and Aguilar-Castellanos, 2016).

CROP PHYSIOLOGY

Quinoa is an herbaceous plant, has wide leaves and polymorphous (different forms in the same plant), the flowers are small and lack petals. They are hermaphrodite and self-fertilize. The grain is dry and measures 2 mm in diameter. It is an annual growth crop, a diploid allotetraploid (2n = 4x = 36), with 36 somatic chromosomes, a dicotyledonous species that belongs to one of the 250 species of the generous *Chenopodium* (Amaranthaceae), and which has now generated enormous interest among farmers, researchers and responsible Politicians around the world, so their implementation outside the

Andean region has been very encouraging. Quinoa seeds can tolerate water loss and maintain viability, recovering vital functions when rehydrated, as well as having the ability to germinate near zero temperatures and tolerance to short exposures to frost (Ceccato et al., 2014). Its growth and development are determined by plant genetics, the environmental conditions to which it is exposed and by biotic factors such as pests and weeds competing with the crop.

Quinoa is a short-day photoperiod plant (physiological reaction of the plants to the duration of the day or night), although it also shows a wide adaptation to different photoperiods for its flowering. Its flowers are sensitive to cold (sterilization of pollen) and to induce flowering or before anthesis. The plant requires a period close to 15 short days in which the duration of the night is greater. If there is a greater number of short days and there is an increase in temperature during the vegetative period, the vegetative until the anthesis is shortened, the development of the flower enters a functional state suitable for the pollination process (Mengel and Kirkby, 2001; Gómez-Pando and Aguilar-Castellanos, 2016). The varieties of the highlands of Peru, Bolivia and the Quinoa of the sea level are those of less sensitivity to the photoperiod with lower length of the vegetative cycle until anthesis, since this condition is influenced by the altitude on the level of the sea in the zone of Origin of Quinoa (Gómez-Pando and Aguilar-Castellanos, 2016) (Fig. 1).

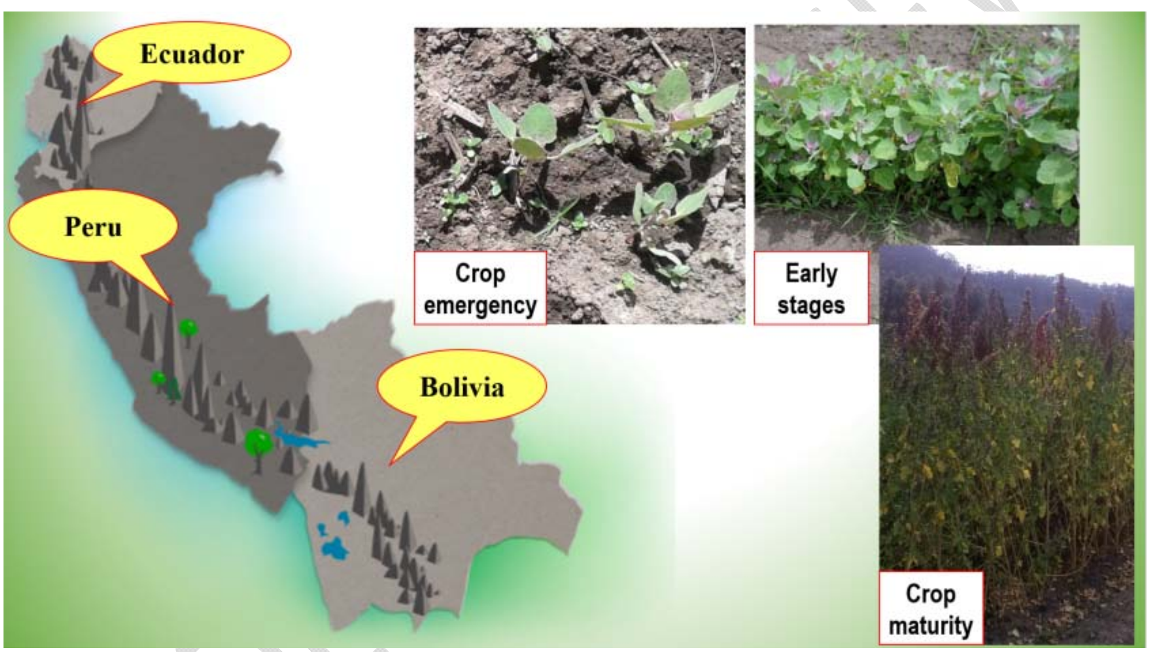

Fig. 1. Countries with the main production of quinoa in South América and crop growth.

Quinoa is an efficient crop regarding water use despite being a C3 plant, it possesses anatomical, morphological, and phenological and biochemical mechanisms that allow it to escape the moisture deficit and withstand the lack of water during drought, main causes of stress affecting growth and performance. Mujica et al. (2012) indicated that among the mechanisms of resistance at physiological level it is the closure of stomatal, stomatal adjustment (decrease of water potential), progressive activation of drought genes and alteration in the expression of proteins in vegetable tissues. Jacobsen and Mujica (1999) pointed out that the hydric relations in quinoa are characterized by having low osmotic potentials, which fluctuate between – 1.0 and – 1.3 MPa, observing a moderate development in the level of adjustment osmotically of -0.3 MPa. In the branching phase, this low osmotic potential of quinoa can be a mechanism of drought tolerance that is reflected in the maintenance of turgor and relative high conductivity stomatal. The process of closing the stomatal when the mesophyll begins to suffer dehydration is regulated by the abscisic acid (ABA). The ABA content in the leaf increases due to the decompartmentalization and redistribution from the chloroplasts of the cells of the mesophyll to the synthesis and transport from the roots, being released to the apoplast to reach the cells guarded through the transpiration current (Zhang and Outlaw, 2001).

On the other hand, Jensen et al. (2000) determined that the gaseous exchange, photosynthesis and conductance of quinoa are within the normal ranges of the C3 plants, showing a similar photosynthetic rate (22 µmol m^{-2} s) in the branching, flowering and filling of grain. However, stomatal conductance (g water) has different behaviors, being higher in the ramification 0.3-1.0 mol m^{-2} s, less at 0.3-0.6 bloom and in grain filling reached 0.2 to 0.7 mol m^{-2} s. The water needs most reflected by quinoa correspond to flowering and grain filling.

The reason for water to limit crop production is that plants can reach up to 90% water in their composition and use it in large quantities to facilitate metabolic processes, movement of nutrients and compounds within and between cells, and to cover water losses due to transpiration (up to 97%). Only a small amount of water absorbed by roots remains in the plant biomass for use in growth (2%) or biochemical processes (1%) (Taiz and Zeiger, 2010). Water loss by transpiration is an inevitable consequence linked to the process of photosynthesis, where the absorption of CO_2 is coupled to the loss of water through a diffusion process. When CO_2 diffuses into the leaves, water vapor diffuses into the atmosphere, and for each molecule of CO_2 absorbed, around 400 molecules of water are lost. This is because the gradient leading to water loss is much higher than that to absorbed CO_2. This unfavorable exchange has had an important influence on the evolution of the shape and function of plants (Moreno, 2009; Taiz and Zeiger, 2010).

CROP VARIETIES

Bolivia is the country that has worked the most in improving quinoa´s production and quality. Hence, varieties obtained by genetic improvement through hybridization or selection in this country are: Quinoa Real, Jamas, Sayaña, Chucapaca, Kamiri, Huaranga, Ratuqui, Samaranti, Robura, Toledo, Padela, Utusaya, Mañiqueña, Señora, Achachino, Copeña (Aroni et al., 2003; Bojanic, 2011). Peru has also conducted some research regarding quinua, and have obtained the following varieties: Yellow Maranganí, Kancolla, Blanca de Juli, Cheweca, Witulla, Salcedo-Inia, Quillahuaman-Inia, Camacani I, Camacani II, Huariponcho, Chullpi, Roja de Coporaque, Ayacucho-Inia, Huancayo, Hualhuas, Mantaro, Huacataz, Huacariz, Rosa de Yanamango, Namora, Tahuaco, Yocará, Wilacayuni, Pachus, Rosa de Junín, Blanca de Junín, Acostambo and Blanca Ayacucho (Mujica et al., 2004; Bojanic, 2011). Among the three major producers of quinoa, Ecuador is the country with the less research regarding this crop and with a smaller number of varieties being cultivated among its area, which include: Tunkahuan, Ingapirca and Pata de Venado (Table 1).

Most of the research conducted in Ecuador has been led by the Instituto Nacional de Investigaciones Agropecuarias (INIAP); therefore, the largest production of quinoa in Ecuador belongs to the variety INIAP Tunkahuan, collected from the germplasm bank of the Carchi province, which is characterized by having a white grain with low content of saponin "sweet", grain of round shape and flattened, with a round of 16% protein, a electrolytic weight of 65 kg HL^{-1} and its vegetative cycle is 180 to 220 d (INIAP, 2010; PROECUADOR, 2015). This variety is the most desired by the industry for its grain homogeneity that facilitates the subsequent processing. The selected *Ingapirca* variety of the germplasm bank of Peru and introduced to Ecuador, is a sweet quinoa, precocious, with an average productivity of 1500 kg ha^{-1}. *Pata de Venado* is a variety of sweet and precocious grain (130 to 150 d), which has an average productivity of 1200 kg ha^{-1} (Peralta et al., 2014; Nieto et al., 1992; Peralta, 2009).

Table 1. Main characteristics of some quinoa's varieties that are cultivated in Latin America.

Variety	Altitude or region	Vegetative cycle	Grain		
			Color	Size	Quinoa type
Ecuador					
Tunkahuan	2200-3200	Medium	White	Medium	Sweet
Pata de Venado	3000-3600	Medium	Cream	Medium	Sweet
Imbaya	2400-3200	precocious	White	Medium	Bitter
Cochasquí	2500-3500	Late	White	Medium	Bitter
Ingapirca	3000-3600	Precocious	White	Medium	Sweet
CH de Saquisilí	2900-3300	Late	White	Small	Sweet
Porotoc	3100	Late	Cream	Small	Bitter
Chimborazo	2780-3400	Late	Cream	Small	Bitter
Perú					
INIA 431-	High plateau and coast	Late	Cream	Big	Sweet

Altiplano					
INIA 427-Amarilla	Inter-Andean Valley	Late	Yellow	Big	Bitter
INIA 420- Negra	High plateau, valleys and coast	Late	Black	Small	Sweet
Amarilla Marangani	Inter-Andean Valley	Late	Orange	Big	Bitter
Bolivia					
Real	3700 y 4200 (High plateau)	Late	White, black, red	Big	Bitter
Del Valle	2000-3000	Late	White	Medium	Bitter
Sajama	High plateau	Late	white	Big	Sweet

Adapted from: INIAP (2010); Apaza et al. (2015); Basantes (2015); Gómez-Pando and Aguilar-Castellanos (2016).

PRODUCTION VOLUMES

According to the alimentary and agricultural statistic FAO (2015), quinoa´s production was increased in countries like Bolivia, Peru and Ecuador; especially due to new varieties with some characteristics desirable for commercialization. The production of quinoa in the Andean region in 2015 was 180000 Mg in an area of 191000 ha, being Peru the greatest producer with 105000 Mg in 69000 ha, and consolidate at the first producer in the word, followed by Bolivia with 75000 Mg (121000 ha) and Ecuador with 12000 Mg in 7000 ha (Fig. 2). These three countries are the top producers of quinoa of the word. In Ecuador, the quinoa is production in the Sierra Region, from 2500 to 3600 masl, according to MAGAP (2014a), the production of quinoa has growth and it is estimated that there are 7500 ha of quinoa with a production of about 12000 Mg. In general, quinoa productivity ranges from 1500 to 3000 kg ha^{-1} in the Andean Region, with an average of 2200 kg ha^{-1}. Genetic improvement tests carried out since 1990 in India have shown that quinoa can be successfully cultivated in this country obtaining yields of 9.83 Mg ha^{-1}.

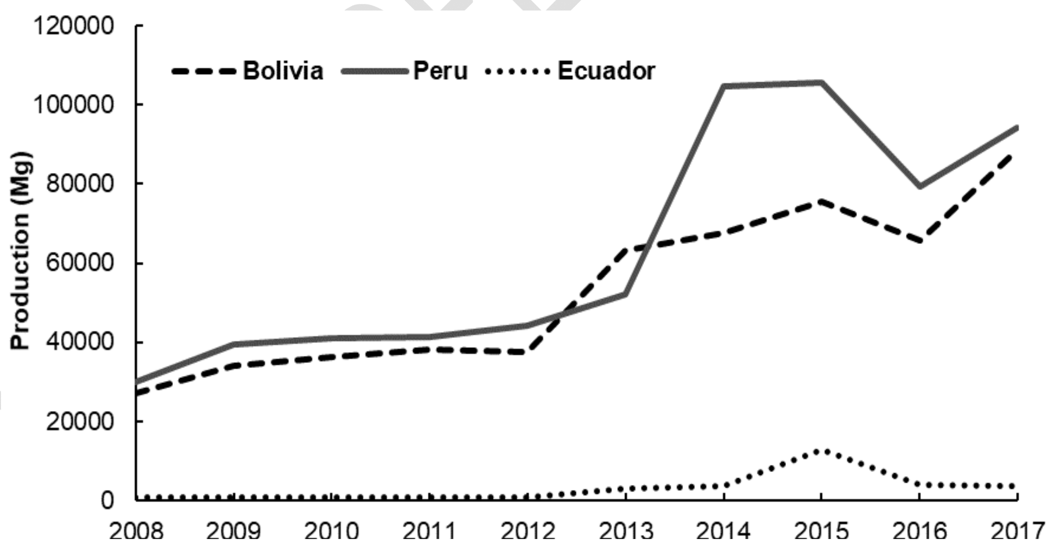

Fig. 2. Quinoa production in Bolivia, Peru and Ecuador in the last decade. Source: FAO (2015).

INTERNATIONAL MARKET

Quinoa is still a new product in international markets, with great potential for trade production and expansion. The cultivation of quinoa in Latin America is led by countries such as Peru and Bolivia, which are the main exporters of quinoa in the world, where Ecuador also has considerable participation. The main markets of the product are the USA, Canada, France, Holland, Germany and the Netherlands. According to Dueñas (2014), due to the global importance of this crop in food safety and the improvement of the nutritional habits of the population, its production has been rising since 2008; in 2012 production increased by 42% compared to 2008, and the main producers were Peru and Bolivia, although Peru has better yields than Bolivia, whose harvested area is almost twice as much as the Peruvian.

There is an increase in the demand for quinoa by American and European countries, where the USA remains the largest importer of quinoa, followed by Canada (Fig. 3). In the case of Latin America, Brazil is the country that has shown a clear trend of consumption and importation of quinoa in the latest years.

According to MAGAP (2013), the fate of quinoa production depends on the market price and availability of land, there are families in which 100% of what is produced is for self-consumption others sell between 10% and 50% to local markets. A model of expansion of quinoa, without regulation, contributes to the volatility of the prices of the product becoming speculative (3500-4000 US \$ Mg^{-1} FOB). It is a product with the possibility of traditional and organic management for its rusticity and little demand, its variety of ecotypes and their adaptation to marginal lands.

According to Valenzuela (2016), the demand for quinoa has diversified and official export records highlight the significant increase in imports, especially from the USA, which in 2005 imported 544 Mg and in 2014, its imports were of 26000 Mg. The number of importing countries in the European Union has also been added, such as France, Holland, Germany, Italy, Spain; Surpassing its imports in the year 2014 the 18000 Mg. In 2012 the same group of countries did not exceed 9000 Mg. In the Asian region, imports from the year 2014 exceeded 2400 Mg, which have been led by Israel and Japan; although in the last year Kuwait is importing quinoa almost at par with Japan on 350 Mg.

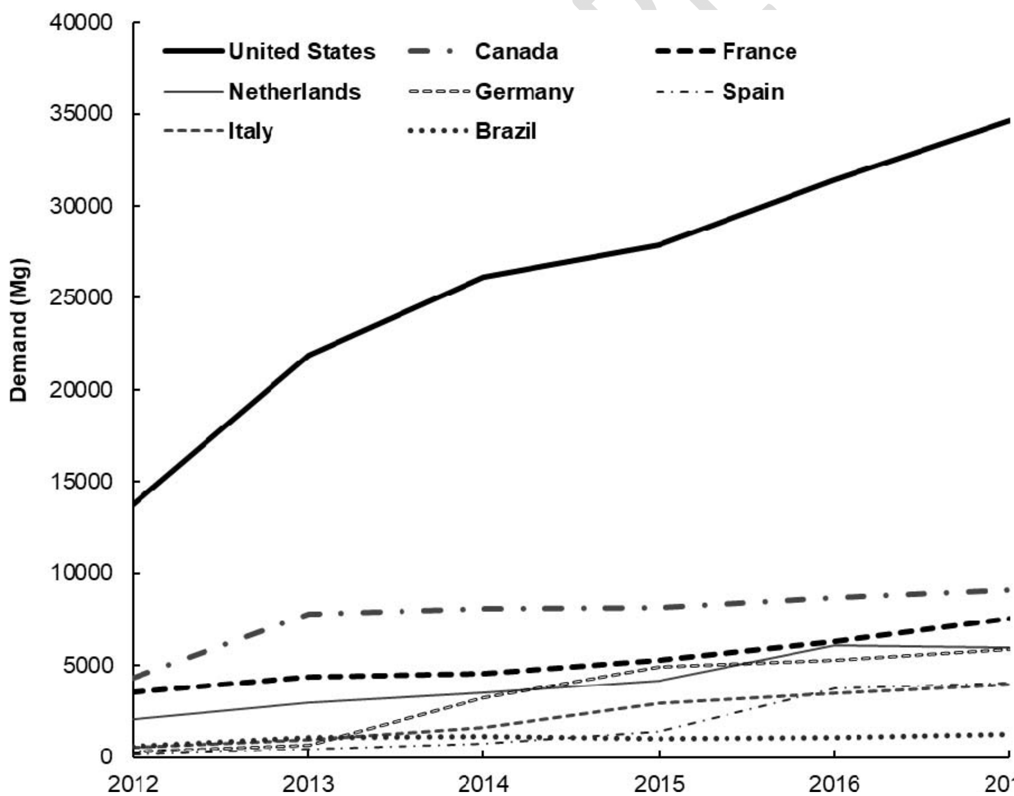

Fig. 3. Demand of quinoa in international markets. Adapted from: Valenzuela (2016), Dueñas (2014) and ITC (2017).

CLIMATE

Quinoa may be the crop that most adapts to a wide variability of climates from the desert, sandy and dry to the cold, dry and/or humid, although in temperate and cold climates is where it reaches the highest productivity (Orsag, 2010) and supports the presence of frost and droughts. Quinoa is an efficient crop regarding water use despite being a C3 plant; the crop requires an average precipitation between 400 to 1000 mm, with optimal rainfall between 500 to 800 mm. The climate of the Sierra of Ecuador is very varied, due to the presence of the Andes; however, principal varieties are adapted to altitudes from 2600 to 3600 masl, although there are varieties adapted to the Andean Valleys.

The distribution of the multi-year precipitation varies month by month in Bolivia (Oruro Potosí La Paz Cochabamba Chuquisaca/Sucre Tarija), in Peru (Puno Arequipa Ayacucho/Quinua Junín Cuzco Cajamarca) and Ecuador (El Prado/IASA Izobamba Otavalo Salcedo Riobamba), considered world-wide as the largest producers of quinoa (Fig. 4). Ecuador has the highest values (1060 mm) annual rainfall, followed by Peru (820 mm) and Bolivia (550 mm) this may be because according to the latitudinal positions, Bolivia and Peru to be further south to Ecuador have the most variable climatic conditions in special the precipitation, which is less. According to this distribution of precipitation in these countries in most months of the year are covered the water needs of the cultivation of quinoa, although there are some months in which water should be supplied in the form of irrigation, in the case of Ecuador is from June to Mid-September, with an irrigation sheet 0.75 to 2 mm. The rainy season or winter lasts from October to May and the summer from June to September.

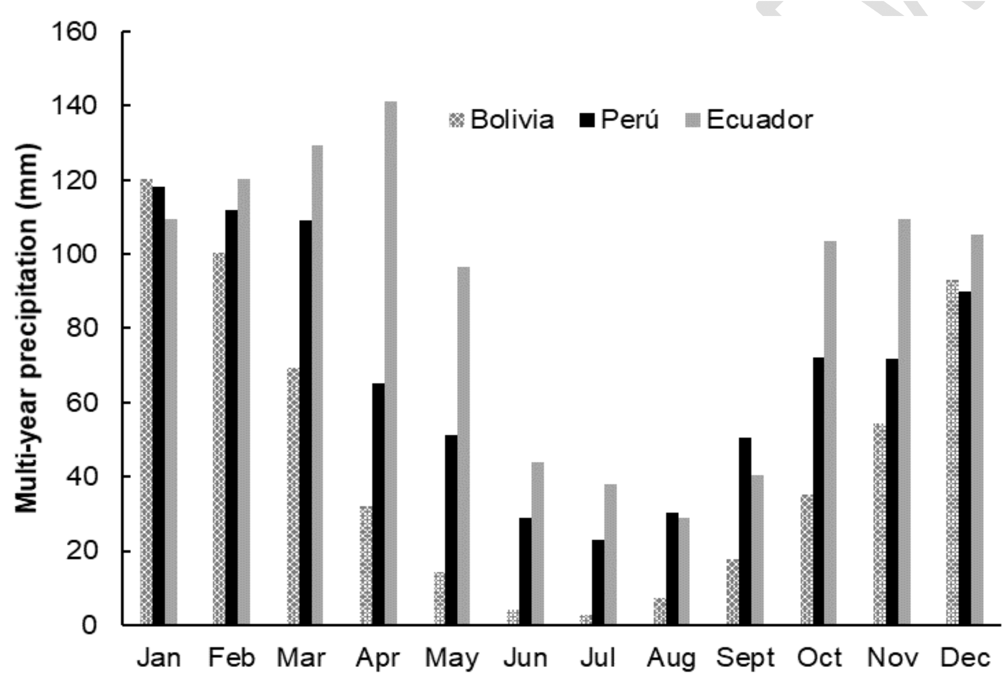

Fig. 4. Distribution of multi-year precipitation series 2008-2017 (Ecuador); in Bolivia and Peru historic data. Source: INAMHI (2018a, 2018b); Climate-data (2018).

As for the temperature quinoa requires an annual average of 10-18 °C with an oscillation of 5 to 7 °C (CARE Peru, 2012), although it can withstand up to -4 °C in certain phenological stages, being more tolerant in the ramification and the most susceptible during flowering and grain filling. The luminosity of 5 to 7 h solar light day^{-1} is suitable to meet photosynthetic processes and transpiration, although it should quinoa is in the group of C4 plantas, because it reduces the process of photorespiration and the plant regulates the stomatal of according or weather variations to avoid water loss. Regarding the multi-year distribution of the temperature of quinoa-producing sites, Bolivia is the country with the highest temperature variation in the year with a variation ranging from 8.9 to 15.4 °C; Peru has a variation of 6.3 to 13.1 °C and Ecuador has lower temperature variation from 12.8 to 13.9 °C (Fig. 5).

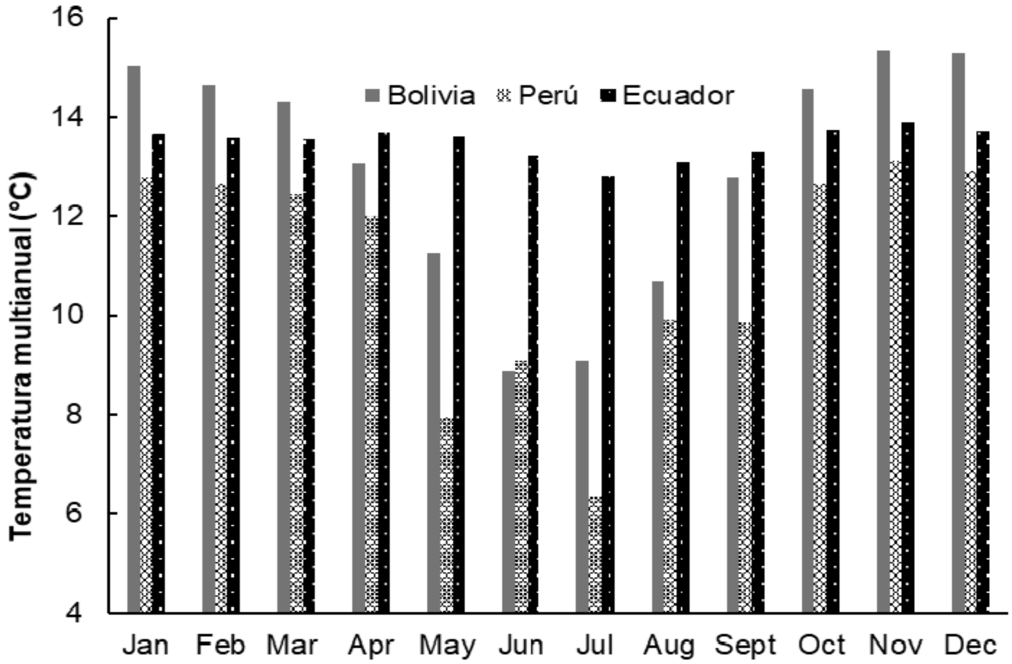

Fig. 5. Distribution of multi-year temperature series 2008-2017 (Ecuador); in Bolivia and Peru historic data. Source: INAMHI (2018a, 2018b); Climate-data (2018).

In Ecuador quinoa is mostly produced between 2500 to 3600 masl, and according to the Holdridge's (1967) classification system for life zones, this altitude corresponds to the low floor altitudinal montane to the alpine floor. The objective of this zoning is to determine the areas where environmental conditions are like group and analyze different biotic populations and communities, and to take better advantage of natural resources. The classification is made on the basis of precipitation and temperature of the area; for example, the site San Fernando-El Prado, near Quito-Ecuador, is one of the places where quinoa grows without main issues at an altitude of 2800 masl, average multi-year temperature of 14 °C; average multi-year precipitation around 1250 mm, relative humidity 68%, sun brightness amount of 4 h day^{-1}; weak winds of 2 m seg^{-1} and pressure of 736 HPa (MA-56, 2018). This site corresponds to the humid forest, flat altitudinal low montane, temperate latitudinal region; the province of humidity corresponds to humid with an evapotranspiration average of 0.75 mm day^{-1}.

CULTIVATION SYSTEMS

Quinoa is produced in monoculture or in association with conventional crops, with use of minimum resources compared to other crops. Farmers of Ecuadorian highlands cultivate quinoa in small areas and/or associate it with two or more crops, for example, quinoa-potato (*Solanum tuberosum* L.), quinoa-snatch (*Lupinus mutabilis*) and interspersing or rotating with bean (*Vicia fabae*), oca (*Oxalis tuberosa*), melloco (*Ullucus tuberosus*) or potato destined for self-consumption. Under this system of association and rotation of crops, the farmer has been trying to promote soil fertility, under a production of manual character and with a family participation. However, in the last two decades, given the demand for quinoa, some farmers have encouraged planting in larger extensions and in the form of monoculture.

Under this situation, the monoculture, the mechanization of soil tillable by ploughing, the lack of rest and crop rotation would lead to the degradation of the soils with losses of the organic matter (OM) of the superficial layer, which is the soil profile fertility support representing the soil N reservoir (around 95 % N), essential element for plant growth, and finally as a consequence of monoculture pests and diseases are perpetuated over time. Different research studies carried out in several countries have shown that the planting of a culture continuously in the same field (monoculture), causes its gradual deterioration (degradation of its physical, chemical and biological properties), with the resulting loss of productivity (Orsag, 2010). According to Peralta (2009), quinoa is part of an associated or multiple crop system; rarely found as monoculture, the most frequent associations are maize (58.7%), with potato, oca and melloco in a lesser percentage; multiple systems in which more than two crops are found to represent 21%, while monocultures just 10%.

PESTS AND DISEASES

In the Andean region exists a diversity of microorganism especially insects and fungus that affect the quinoa crop (Table 2). Although quinoa can tolerate unfavorable growth conditions, pests such as birds, insects, rodents and various diseases can cause significant yield losses. The presence of diseases and pests often depends on the density of the plant, the presence of weeds, the relative humidity, and nutritional status of the field and the rotation of crops used. Preventing actions against pests and diseases in quinoa is of paramount importance, and an essential component of integrated pest management. The disease occurs when the plant has some mechanical damage, product of a slush or frost and is propagated by favorable conditions of high humidity (presence of rains). First by the wound are introduced bacteria, which produce decomposition and then introduce the fungi and causes harmful damage to plants, the pathogen to infect a plant gets its nutrients neutralizes its defense reactions and causes negative effects on their physiology.

Pacheco (2004), it indicates that the quinoa moth is considered one of the most damaging pests, for this reason the non-application of bioinsecticides (a living organism: fungus, bacteria, virus and/or chemical substance present in the plant, can repel or kill the Leads to losses of 40% or more of the production. The best way to do pest control is through prevention, planting selected seeds of resistant or tolerant varieties of pests and diseases, certified and disinfected; avoiding monoculture; rotating (tubers, cereals, cultivated pastures); avoiding excess moisture and flooding.

In necessary cases and if the infection is meritorious, biological or chemical control can be carried out, although it must be present that the organic production and control of the crop is the most appropriate to produce healthy and nutritious food for the internal consumption and the export.

Table 2. Main pests and diseases of quinoa.

Common name	Pathogen	Symptom	Control
		Diseases	
Mildew of quinoa	*Peronospora variabilis*	Stains on leaves and stems, first light green, then yellow. It produces dwarfism and defoliation. Appropriate conditions: High relative humidity, cloudiness and rain.	Use disinfected seed. Resistant varieties. copper fungicides
Foliar Stain	*Ascochyta hyalospora*	Chlorotic stains on leaves.	disinfected seed
Leaf stain (crow's eye)	*Cercospora sp.*	Necrotic spots on the leaves, circularly and irregularly, Gray in the center surrounded by a dark halo. Appears from germination to panic.	Seed disinfection. Good soil preparation, crop rotation. Contact and systemic fungicides
Root rot or mal seedlings	*Rhizoctonia sp., Fusarium sp, Pythium sp.*	It appears in the cotiledonal phase (emergency) with strangulation in the stem of the seedlings at ground level. Radicle rot	Healthy seed, drainage, crop rotation. Fungicides (Capture Benomyl)
Pointed Stem stain	*Phoma sp.*	It affects the stems and petioles. Strangulation and death. Pointed lesions of light gray in the center and brown edges. Black dots that are the pycnidia of the fungus.	Resistant varieties. Crop rotation.
Green Mold	*Cladosporium sp.*	Small patches of green color, in leaves, panicle.	Seed. Soil preparation. Rotation. Density plants.
Bacterial stain	*Pseudomonas sp.*	Irregular spots moistened in stems and leaves at the beginning. Then dark brown	Avoid the use of seeds of infected plants.

		with deep injuries. It may appear in the milky grain phase.	
		Plagues	
Chopping worm. Suckers. Green aphid. Quinoa bedbug.	*Agrotis ípsilon; Macrosiphum euphorbiae; Liorhyssus hyalinus*	They infest the stems, in newly emerged and developing plants.	Pre-sowing irrigation. Weed-free. Crop rotation. Use of insecticides
Chewing foliage. Army worm. False meter. Pulguilla jumping. Mine fly.	*Spodoptera eridania*; *Chrysodeixis includens; Copitarsia sp; Epicauta spp. Epitrix spp.; Liriomyza sp.*	The larvae when they emerge are fed by scraping the epidermis of the leaves. Developed larvae voraciously consume the foliage and can climb to the panicle to feed on the developing flowers and grains.	Keep the field weed-free. Use low-impact insecticides. Weed-free Use of parasitoids (*Trichogramma sp*.). Entomopathogenic (*Beauveria sp.)*
Moths and insects of the panicle	*Eurysacca melanocampta y E. quinoa; y Helicoverpa quinoae*; *Chloridea virescens* (= *Heliothis*)	The quinoa moth is considered one of the most damaging pests of quinoa (loss of 40% grain). Attacks throughout the vegetative state, leaves inflorescences	Keep the field weed-free. Use low-impact insecticides. Weed-free. Use of parasitoids (*Trichogramma sp.)*. Entomopathogenic (*Beauveria sp*.)

Adapted from: FAO (2016).

SOIL TYPES

Quinoa adapts well to different types of soils, preferring the loam-sandy to loam-clay with good drainage, because it is very sensitive to excess moisture especially in the first stages (Jacobsen and Sherwood, 2002). It requires fertile soils with a high content of OM, pH slightly between 6 and 8, although it can also grow on more adverse soils, sandy, infertile and clayey. The plant is demanding in N and Ca, moderately in P and K. According to Gómez-Pando and Aguilar-Castellanos (2016), quinoa can tolerate a wide range of pH, from acid soil pH 4.5 (in the inter-Andean valleys of northern Peru) to very alkaline pH 9 (Peruvian Bolivian High plateau), and can grow in extreme conditions of salinity of 52 dS m^{-1} (Murphy and Matanguiban, 2015; Jacobsen et al., 2001), but the best soils can be between pH 6.0 to 8.5 and with an electrical conductivity of 12 mmhos cm^{-1} (SEPHU, 2010). Peterson and Murphy (2015), in a study in four quinoa cultivars on tolerance to salts, showed a high level of tolerance to salinity, much higher than other crops considered tolerant to salt, such as barley, and also determined that the cultivars had a greater tolerance to Na_2SO_4 than to NaCl at levels of electrical conductivity of 16 and 32 dS m^{-1}.

SOIL MANAGEMENT: COMMON PRACTICES AND CHALLENGES

Prior to planting

The sowing of quinoa is done by placing the seed in the soil directly, but because the seed is small for planting, good soil preparation is needed to create a favorable soil structure so that the seedlings emergence is fast and allows young plants to have quick access to vital resources of nutrients, water and aeration. The preparation of the ground in general consists of ploughed, cross/harrow and furrowed, using tractor or by hand.

Tillage is a common practice that consists in the preparation of the soil to provide the favorable conditions for crop development and growth. Both the conventional tillage and the minimum tillage system have the same objectives. Minimum tillage to reduce soil erosion is limited to the removal of soil from surface layers or a small opening for each row of the crop, for which light machinery is used; this can be a critical factor in maximizing productivity, but it is not a common practice in South America (Pantoja, 2014). However, the main problem for Andean rural communities is the lack of machinery (tractors and agricultural implements) for land preparation and crop management. Therefore, most field work is done by hand, which results in deficient soil preparation and increases production costs. For that reason, local governments in Ecuador are trying to provide with equipment to farmers association and educational institutions, but these initiatives have to continue to be successful in helping small farmers (MAG, n.d.).

Post-planting

Basantes (2015) indicates that the management of the cultivation of quinoa consists of maintaining an aerated soil, free of weeds, being able to make one or two hilling depending on the type of soil and presence of winds. Pest control should be done depending on the emergence threshold of the pest, although with good nutrition, adequate plant density and low incidence of pests, it is not necessary to do so.

FERTILIZATION AND NUTRITION: SUCCESSES AND MISTRUTHS

Several small farmers do not apply fertilizer to quinoa fields; however, fertilization is very important in the cultivation of quinoa because of its high demand for nutrients. Quinoa is not fertilized especially when it is grown as a rotation crop (like after potato harvesting), in which case it is assumed that quinoa will uptake the residual fertilizer remaining in the soil. Nevertheless, for good growth quinoa needs especially macro elements such as N, P, K, Ca, Mg, S and need small amounts of micro elements (Fe, Mn, Cu, Zn, B, Mo). The dosing of fertilization must consider the potential of the varieties yield and the availability of nutriments in the soil (Pantoja, 2014). High yields of quinua (from 6 to 7 Mg ha^{-1}) have been achieved under field conditions with the application of 300-120-300 kg ha^{-1} of N-P-K through the irrigation system, in sandy loam soils and at 1200 masl (Gómez-Pando and Aguilar-Castellanos, 2016). However, there is a lack of information regarding nutrient inputs and output of the soil-crop system (See the N example in Fig. 6).

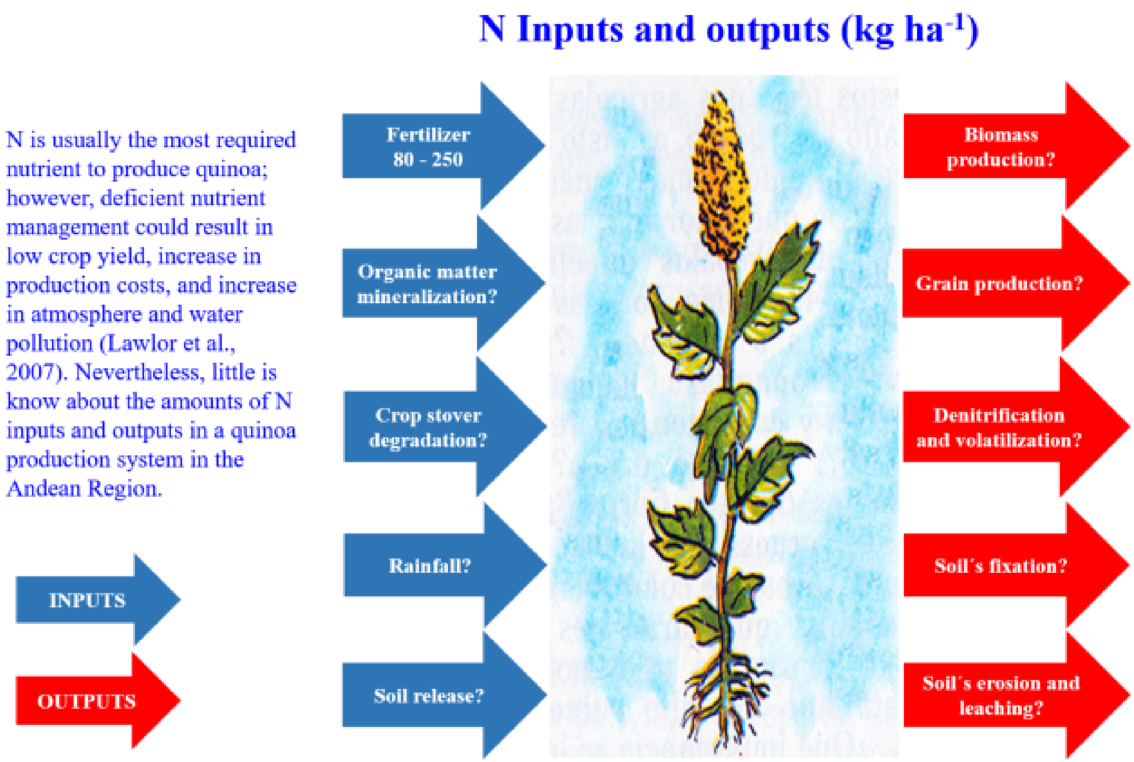

Fig. 6. Possible inputs and outputs of N in a quinoa production system.

Murphy and Matanguiban (2015), they point out that the investigations of fertilization in quinoa, are limited and thus cites Erley et al., (2005) reporting that quinoa responds positively to fertilization with N, producing on the 3.5 Mg ha^{-1} with a fertilization of 120 kg N ha^{-1}. The dynamics or movement of nutrients in the soil is a fundamental mechanism that has to do with the accumulation; absorption and leaching of nutrients in the soil-plant system, the availability of such nutrients for the plant determine the performance of the Culture. An efficient management of the crops requires that these generate a developed root system that allows to capture the water and mineral nutrients effectively, although the mobility of some nutrients in the solution of the soil is low, requiring proximity of the roots for absorption. Soil analysis is one of the best tools available to determine the quantity and availability of soil nutrients for plants, as well as the amount of nutrients that must be applied in the form of fertilizers to achieve high productivity and without cause impact to the environment.

Mujica et al., (2012) notes that quinoa is demanding in N, P, K and Ca, so it requires good fertilization and composting. The levels to be used depend on the richness and nutrient content of soils where quinoa will be installed, the rotation used and also the level of production to be obtained, recommended the incorporation of manure in the time of rupture of soils between 4 to 10 Mg ha^{-1}. According to García et al., (2017); García, et al., (2015) the applications of chemical fertilizers more organic mineral, presented the best results in dry and fresh weight of the plant and panicle, yield in grain, chlorophyll content, number of leaves and number of panicles per m^2, so, the use and application of organic-mineral fertilizers was an important option to fertilize that favored the yield and profitability of quinoa cultivation.

In Ecuador fertilization in the management of quinoa cultivation is not a very common practice, quinoa crops obtain indirect fertilization of the main crops that are fertilized or depend on the nutrients applied to the previous crop that is the potato. In part, lack or low fertilization explains the productivity of 500 to 1500 kg ha^{-1} (MAGAP, 2014b). On the other hand, studies of fertilization with N in quinoa carried out by the INIAP, (2010); Basantes et al., (2015), indicate that the crop to produce 2 to 3 Mg ha^{-1} needs between 80 to 250 kg N ha^{-1}. According to Nieto et al., (1992) quinoa responds to both chemical fertilization and organic fertilization, recommended to apply 80-40-30 kg ha^{-1} of NPK and 5 to 10 Mg ha^{-1} of organic fertilizer. In low-fertility soils, it is recommended to apply 80 kg of N and 40 kg of P ha^{-1}; it is covered with 100 kg ha^{-1} of 18-46-00 applied to sowing, plus 150 kg of urea or 200 kg ha^{-1} of ammonium nitrate to weed or hilling (Peralta et al., 2014).

Although in practice the farmer does not fertilize but takes advantage of the nutrients of the previous crop, CARE Peru (2012) indicates that N is the "engine of plant growth" and the plant will show its efficiency shortly after its application, where plants will develop a dark green color and grow more vigorous, but on the other hand the excess N, can cause tipping, greater competition of weeds and pest attacks, with substantial losses of crop production. In addition, N not absorbed by the crop is lost in the environment. As for P, quinoa responds to the application between 60 and 120 kg ha^{-1}, for a productivity of 1190 and 2120 kg ha^{-1}, respectively. It is usually obtained less than 1000 kg ha^{-1} of quinoa grain in traditional crops and rainfed conditions. With the use of adequate levels of composting, disinfection of the seed, sowing in furrows, control of weeds, the Sajama variety has produced up to 3000 kg ha^{-1}, being the commercial average 1500 to 2500 kg ha^{-1}, although in practice, the peasants do not fertilize the quinoa, this takes advantage of the nutrients applied to the previous crop that is usually the potato.

In Bolivia, due to the soil and climate conditions of the Bolivian Highlands, one of the most important activities to improve the yield of quinoa is fertilization since soils have little OM. In improved crops, granular and foliar N fertilization is used. Quinoa is a plant demanding in nutrients, especially N, Ca, P, K, so it requires a good fertilization, equivalent in average to the formula: 80-80-00 per hectare, no potassium for the availability in the soils of the Andes (Tapia, 2000). Miranda et al., (2013) determined that to produce yields of 3000 kg ha^{-1} the appropriate dose was 120 kg of N and that the quinoa extracts from the soil between 45 to 50 kg of N. According to PROINPA Foundation (2005), in the production of conventional quinoa take advantage of the residual effect of potato cultivation and supplement with urea at level 20 to 30 kg ha^{-1} is adequate, although it can also apply foliar fertilizers and it is recommended to incorporate green manure from cultivated and wild legumes to take advantage of the fixed N and OM for quinoa. As an effect of the demand of the international market for organic quinoa production in Bolivia, a slow but auspicious practice of organic fertilization is beginning, especially with the use of crop residues and livestock by-products such as manure, which are incorporated in different ways and in quantities according to their availability.

HARVEST AND POST-HARVEST MANAGEMENT

The manual harvest (with sickle) is the most common and consists of cutting the plant between 15 – 30 cm from the soil, leaving the stubble on the same soil, which helps the soil conservation and is made when it is detected that the grain offers resistance to pressure between the nails, the plant has been defoliated prior to the acquisition of yellow or red color depending on the variety, the panicle acquires the typical color of maturity, the grains can be seen in the panicle through the opening of perigone, which are indicative of physiological maturity (Aroni, 2005). Another way of harvesting quinoa is to start the plant and leaving in piles in the field to dry, this method is not highly recommended because it removes the roots of the soil instead of leaving them as OM, reduces soil fertility, contributes to soil erosion and finally soil particles can be mixed with grain (Bojanic, 2011). The mechanical harvest is little practiced by the lack of machinery and proper management of the crop; however, it can be done, using combined machines, requiring that the quinoa lot is free of weeds, especially those of small seeds, difficult separation in the cleaning and selection process. Once the cut panicles are dry, the threshing is executed, hitting the sheaves with a rod on tents or plastics, if the lots are very small you can use the stationary threshers used for cereals, although they must be adapted to the grain of quinoa. Which is smaller and lighter, in order to avoid losses. When the harvest is not timely and rains occur, the grain of quinoa germinates in the same plant; so, the final product is damaged.

Storage: Dry and clean grain must be stored in closed containers or in narrow-tissue coasts, in clean, dry warehouses, protected from the attack of rodents and insects, with air circulation and with a content of 14% moisture in the grain. The classification and cleaning of the grain is done to obtain a grain of quality and better price for the trade.

Desaponification: The sweet grain or low-saponin varieties require a quick wash with clean water or a light scarified, unlike bitter varieties that need to be washed in abundant water or receive a strong scarified (brushed via dry); before cooking or processing. The consumption of the quinoa grain implies the removal of the husk, in order to reduce its bitter taste. Saponin are a type of secondary metabolite and are the main anti-nutritional factor of quinoa seeds. They are contained in the shell and are responsible for the bitter taste. Its content makes it possible to distinguish quinoa varieties as sweets (< 0.11%) or bitter (> 0.11%). However, their presence is not restricted to the seeds; they are also in the leaves of the plant (9 g 1000 g^{-1}) and in less proportion in the flowers and fruits (Ahumada et al., 2016). It is important to indicate, most of the processing of quinoa grain is done by hand, as there is a lack of processing plants to do this work in small rural towns. In the case of Ecuador, the government has try to provide some industrial equipment to communities, but the lacking of such equipment remains (MAG, n.d.).

NUTRITIONAL VALUE

For its nutritional benefits quinoa has been classified as an alternative source for global food security, especially in those areas where the population does not have access to adequate sources of protein or where there are environmental limitations for the production of food crops, it represents a great potential to improve the living conditions of the population settled in the Andes and the modern world (Bazile et al., 2014).

Bojanic (2011) indicates that quinoa is the only plant food that possesses all essential amino acids, trace elements, vitamins and contains no gluten. According to Risi et al., (2015) the quinoa protein has an adequate balance of essential amino acids AAE, especially lysine, methionine, threonine and tryptophan. The essential amino acids are found in the kernel of the grain unlike other cereals that have them in the exosperm or husk, such as rice or wheat. An amino acid is an organic molecule with an amino group ($-NH_2$) and a carboxyl group (-COOH) and are the basis of proteins. Hence, the cultivation requires nutrients from the soil to satisfy their nutritional needs, which is compensated in a fertile soil or covered by the application of fertilizers to the soil and foliar.

Murphy and Matanguiban (2015) declare that the lipid content in the quinoa seed embryo is higher than in common cereals; this oil is rich in polyunsaturated fatty acids (linoleic and linolenic) and in oleic acid. The main carbohydrate is starch where soluble sugars, i.e. sucrose, glucose and fructose are present at low levels. Quinoa starch is rich in amylopectin and gelatinize at low temperatures (57-71 °C). It also contains significant amounts of riboflavin, thiamine and vitamin C that are not known in cereals. The folate content in quinoa is about 133 mg 100 g^{-1} MS, about 10 times more than in wheat seeds. In addition, quinoa seeds do not contain allergen compounds such as gluten or prolamina or enzyme inhibitors (proteases and amylases) present in the most common cereals.

Despite its healthy nutritional composition several quinoa cultivars contain bitter saponin, secondary metabolites glucose in the seed coating that act as anti-nutrients and toxic elements for birds. Although saponin have negative effects, they also have positive effects, such as reducing serum cholesterol levels, possessing anti-inflammatory, anti-tumor and antioxidant activities, and improving drug absorption through mucous membrane. Saponin also exhibit insecticide, antibiotic, antiviral and fungicide properties. In addition, saponin reacts like immunologic adjuvants and absorption to enhance the mucous and specific antigens (Murphy y Matanguiban, 2015; Carrasco et al., 2003).

QUINOA INDUSTRY

Quinoa (stalk, leaves and grain) in addition to be a human food has other uses within the industry, such as cosmetics, pharmaceuticals and pesticides (Villacrés, 2016; FAO and ALADI, 2014). The grain is a rich food, containing nutritional value higher than most cereals, does not contain gluten, and possesses 10 essential amino acids for humans, which makes it a very complete and easy to digest food. The indigenous populations of the Andes have used the leaves, stems and grains for medicinal purposes, which are attributed healing properties, inflammatory, analgesic and disinfectant. The whole plant can be used as green fodder and the residues of its harvest can be used for animal feed. In addition, various research reveals the potential use of quinoa in the chemical, pharmaceutical and cosmetic industries. For example, starch has potential possibilities of use in the industry due to its small size, in the production of aerosols, pastes, desserts, excipients in the plastic industry, powder and anti-offset powders. In addition, quinoa starch has excellent stability against freezing and retrogradation, which may be an alternative to substitute chemically modified starches (Peralta et al., 2014; Villacrés et al., 2011).

Also, the saponin extracted from the pericarp of the sour quinoa can be used potentially in the elaboration of detergents, toothpaste, shampoo or soaps, which are emulsifying agents of fats, oils and protector of colloidal substances. In addition, the properties of saponin are mentioned as antibiotic and for the control of fungi among other pharmacological attributes. Due to the differential toxicity of saponin in several organisms, it has been investigated on its use as a potent natural insecticide that does not generate adverse effects in humans or large animals, highlighting its potential for use in integrated programs of pest control. The use of quinoa saponin as a bioinsecticide was successfully tested in Bolivia (FAO, n.d.).

The bitter plants with high content of saponin of black grains and dark colors usually are not attacked by insects and in the generality of the cases, the roots act like trap plants of nematodes that attack mainly the tubers (potato, oca, olluco) by this is the custom of harvesting quinoa extracting the root and the whole plant and then use as fuel, both the stump and root where they are adhered nematodes forming nodules as rosaries.

CONCLUSIONS

Quinoa is a tetraploid plant of great nutritional and functional value in the diet, in addition to a wide adaptation to different climatic conditions and soil types, preferring sandy loam to clay loam with good drainage, because it is sensitive to excess moisture, especially in the early stages. For a better production requires fertile soils with high OM content, pH between 6 and 8, but can also grow in more adverse soils. The plant is demanding of macronutrients and it can accumulate as much as: N (3.65%), K (4.2%) and Ca (1.63%), with moderate accumulation of P (0.39%), Mg (0.94%) and S (0.28%). Regarding micronutrients, the grain contains Fe (76 mg kg^{-1}) and Mn (262 mg kg^{-1}), as well as B and Zn.

In addition to be a human food, quinoa (the stem, leaves and grain) has other uses within the industry, such as cosmetics, pharmaceuticals and pesticides. The grain is rich in nutritional terms, because its protein content is higher than most cereals, in addition to having minerals, vitamins, quality of oils and antioxidants, 20 essential amino acids of the 22 needed by humans. Therefore, quinoa has a high nutritional and functional content, as it has does not contain gluten which makes it a very complete food and easy to digest.

Despite the importance of quinoa for Andean countries, especially Bolivia, Ecuador and Peru, it is still a new product on international markets, with great potential for production and trade expansion. Peru remains as the main producer of quinoa but, as is Ecuador and Bolivia, the quinoa production still faces several challenges. These include lack of fertilizer application and management, lack of equipment for field activities and grain processing, and lack of market strategies to make quinoa become a more important food in the internacional market.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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