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Ms Zenesia Phillips- Henry
Faculty of Agricultural Science, University of Guyana, Berbice Campus, Guyana.

Mr. Courtney Bullen
Faculty of Agricultural Science, University of Guyana, Berbice Campus, Guyana.

Correspondence:
Ms Zenesia Phillips- Henry
Faculty of Agricultural Science, University of Guyana, Berbice Campus, Guyana.

Prospects for Quinoa production in Guyana.

Ms Zenesia Phillips- Henry and Mr. Courtney Bullen

Abstract
The inevitable phenomenon of climate change has led to environmental changes which can cause interruptions and major declination in agricultural production across the globe. In Guyana, sea level rise, as predicted to occur within the next decade on the Coastal zones, maybe directly accredited to the effects of climate change. The threat of flooding in this area would not only result in the displacement of the population that reside in this zone, but would also affect all major agricultural activities and industries. As a consequence, food supply and GDP will be severely affected. In the event of the aforementioned, it is imperative that alternative areas for large scale agriculture be developed in less flood prone areas. It may also be necessary to establish crops that are resilient and can be utilized as a staple in addition to the main agricultural product ‘rice’.
Quinoa, ‘the mother grain’ is a hardy crop that has characteristics which enables it to thrive under a wide range of ecological conditions. It has been recognized as being gluten free and carries high nutritive value. In addition to agricultural uses, quinoa is used in the pharmaceutical and cosmological industries thus making it a crop of high economic value.
Five physiographic regions have been recognized in Guyana. Among them is the Hilly Sand and Clay Region (White sand Plateau), located along the north east part of the country. This region has available land and water resources, making it an alternative area for the production of Quinoa. Amelioration of the Tiwiwid Sands may be necessary for optimal production of this crop.
This research examines the prospects of cultivating this crop as a potential alternative for rice which may be affected by the influence of Climate change. It also seeks to examine prospective areas for adaptation of large-scale agriculture, creating scope to benefit Guyana’s economy.

Keywords: climate change, quinoa, ecological conditions, Guyana economic prospects, Guyana’s physiographic regions.

Introduction

In Guyana Climate Change has gradually led to alterations in agricultural production practices that may affect national food security in future. The United Nations Framework convention on Climate Change (UNFCCC, 2011), describes climate change as any shift in climate over a protracted period of time due to natural variability or as a result of human activity. According to the Guyana Climate Change Action Plan 2001, climate change poses threats that may impact sea level rise in the coastal zones of the country. The Guyana National Land Use Plan 2013 predicted the Low Coastal Plain to be 0.5 to 1 meter below sea level. Despite this, it is home to 90% of Guyana’s population. The majority of Guyana’s main agricultural production take place in this region, predominantly rice and sugarcane. The Low Carbon Development strategy estimated that 39% of the aforementioned population that contributes to 43% GDP, live in flood prone areas.
According to Wolff et al. 2020, this phenomenon has caused planetary scale climate warming which led to 2010-2019 being the warmest decade recorded after the 1850’s. This resulted in sea level rise driven by expansion of water volume by virtue of the melting of ice caps and mountain glaciers in all regions of the world. Greenland and Antarctic Ice sheets continue to be lossed as a result of Climate warming, leading to an increase in storm surges and consequential flooding. It is predicted that sea levels will continually rise in the following centuries as glaciers continue to ‘thaw. The Guyana National Land Use Plan 2013 predicts that by 2030 flooding could result in U.S 0.8 billion in losses in GDP affecting 39.3 % people. The effects of climate warming ultimately lead to inland stress and hence an

overall reduction in agricultural productivity across coastal zones. It is therefore imperative that considerations be made for the development of new agricultural lands in less flood prone areas. The establishment of other resistant crop types to be used as a staple may also be necessary to ensure sustainability of Guyana's population.

Quinoa (Chenopodium quinoa Willd.) is an annual herbaceous plant that belongs to Amaranthaceae family, which originated in the Pacific slopes of the Andes in South America (Jaikishun et al., 2019). It is a pseudo-cereal food crop cultivated in several Andean countries of Latin America. Despite it being native to temperate regions, quinoa can be cultivated well in various tropical regions and can adapt to a wide range of climatic conditions (Aguilar et al., 2003; Garcia, 2003, Fuentes et al., 2011). Quinoa is recently gaining global importance due to its excellent protein quality and forbearance to abiotic stresses such as drought, heat, frost and salinity. The Quinoa grain has been recognized as exceptionally nutritious due to its high protein and amino acid content and less carbohydrates compared to rice (Jacobsen, 2003; Wu et al., 2016). Quinoa means "mother grain" in the Inca language and used as a staple food in India, Peru, Bolivia and other parts of the world. The prospect of introducing quinoa to Guyana would contribute to agricultural diversity and create scope for wider choice amongst local consumers. Production of this crop will also ensure national food security while benefiting the economy.

Guyana's National Land Use Plan 2013, recognizes (5) main Physiographic Regions. Among them is the Hilly sand and Clay Region also known as the "White Sand Plateau". This region is located in the northeast central part of Guyana, south of the Coastal Plain. It is about 15m above sea level, has more available land and an abundance of water resources. This makes it a potential alternative area for crop production, given the fact that it is also more accessible than other regions.

Tiwiwid soils are known for their well-drained nature, low nutrient availability, high acidity and low water holding capacity. Therefore, soil amelioration and management of fertilizer application is essential for the production of quinoa on these soils. This research paper is therefore based on the prospects of introduction and production of this crop to be utilized as an alternative staple to rice. It also explores possible regions that may be regarded as potential production sites for successful cultivation of this crop.

Methodology

Sources of information

One of the principal sources of information that was used for the generation of this research paper is the FAO publication entitled The State-of-the-Art Report on Quinoa (2013). This is a compendium of research articles and review papers that cover a wide range of issues pertaining to the botany, domestication and global expansion of this crop as well as its nutritional, economic and ecological aspects, which are covered in this paper. Research articles that dealt directly with crop performance under different ecological conditions were found and used. Research was done using the Guyana's National Land Use Plan (NLUP) to describe the five physiographic regions and determine possible suitability for crop production. Other research papers were generated using google scholarly articles. Papers used were dated from 1965 to more recently 2021. Information for quinoa global trends were collected from the www.statista.com website, for the successful completion of this research.

Structure of the Paper

- Climate Change: A global concern.
- The Quinoa Crop. (Taxonomy, origin, description, uses).
- Quinoa crop requirement and management. (Climate, soil, management, fertilizer requirement).
- Adaptability of Quinoa (Crop tolerance, resistance to pest and diseases).
- Guyana's Physiographic Regions
- Quinoa: Distribution, Economic importance and World Production trends.

Climate change: A global concern

Climate change is one of the most significant issues that the world faces in recent decades. Evidence has shown that humans are changing the earth's climate. These changes ensue the warming of the atmosphere and oceans resulting in sea level rise and decline in Artic Sea ice. (Wolff et al., 2020). Human interface with the climate system through emission of greenhouse gases and changes in land use has increased the global and annual mean air temperature at the surface of the earth by at 0.8^{0}C since the 19th century. It is predicted that the earth can warm by at least another 4^{0}C if emissions are not notably reduced (Feulner, 2015). The impacts of climate change will be quite considerable, posing threats to ecosystems especially along the coast. Drought affected areas are expected to increase with extreme precipitation events occurring with increasing frequency and intensity because of air capacity to hold more water. Coastal areas would be exposed to coastal erosion due to sea level rise. It is anticipated that densely populated low-lying areas will experience flooding due to sea level rise by 2080 (UNFCCC, 2011). A warming climate can contribute to the intensity of heat waves by increasing the chances of very hot days and nights while increasing evaporation on land. This can increase occurrences of drought and create conditions that promotes wildfires. El Niño events favour drought in many tropical and subtropical land areas, while La Niña events promote wetter conditions in many regions (Wolff, 2020).

Climate Change Solutions International (CCSI, 2009) reported that the mean annual air temperature of Guyana, overall, has increased by 0.3°C since 1960, which translates into an average rate of c.0.07°C per decade. This rate of warming is less rapid than the global average of c.0.08°C per decade. The mean annual rainfall for Guyana has increased at an average rate of 4.8mm per month or 2.7% per decade since 1960. Trends in both annual and seasonal rainfall are minimal and not statistically significant. Future predictions for temperature and rainfall for the 2030s, 2060s and 2090s show an increase of warming 1°C, 2°C and 3°C respectively while precipitation is predicted to fall by about 10% by the 2090s, mainly in the northern coastal zone (NLUP,2013)

Global climate change affects the general conditions under which crops are grown mainly due to increased salinization and aridity. Salinity has been predicted to increase at a rate of 10% annually (Hasegawa, 2013). Factors such as excess irrigation and poor drainage, groundwater salinity, sea level rise and intrusion, as well as irregular rainfall contribute to the process of soil salinization. Salt-affected soils cover an area of around 1060.1 M/ha in the world. This figure is continually increasing due to the influence of climate change where soil salinity tends to increase with increased sea level intrusion and temperature and decrease in precipitation (Eswar et al., 2020).

Global warming has become a major concern, now reaching critical levels, hence threatening food security. It is predicted that yield will decrease between 3.1 and 7.4 percent for every 1^0 C temperature increase. It is therefore necessary for farmers to explore crops that can adapt to changing environments and harsher climates (Thiam et al., 2021). Growing population and food demand poses many challenges to global agriculture in the future. It is reported the world population is expected to reach over ten billion by the year 2050. A demand for more food would cause demand for more agricultural lands to be developed (Bouwman et al., 2017).

Climate change can affect water availability, and as a consequence crop water requirement. Crop water requirements are defined as the "quantity of water required by a crop in a given period of time for normal growth under field conditions" (FAO, 2008) Climatic and environmental changes can affect agricultural inputs especially water resources therefore, in order to adapt to this situation of climate change, the introduction of low-water, salt resistant and drought tolerant crops may be necessary (Fathi et al., 2020). The physiological adaptability which allows quinoa to grow under drought and other adverse conditions represents an invaluable opportunity and offers tremendous potential in the face of present and future climate change challenges. (Azurita- Silva et al., 2013).

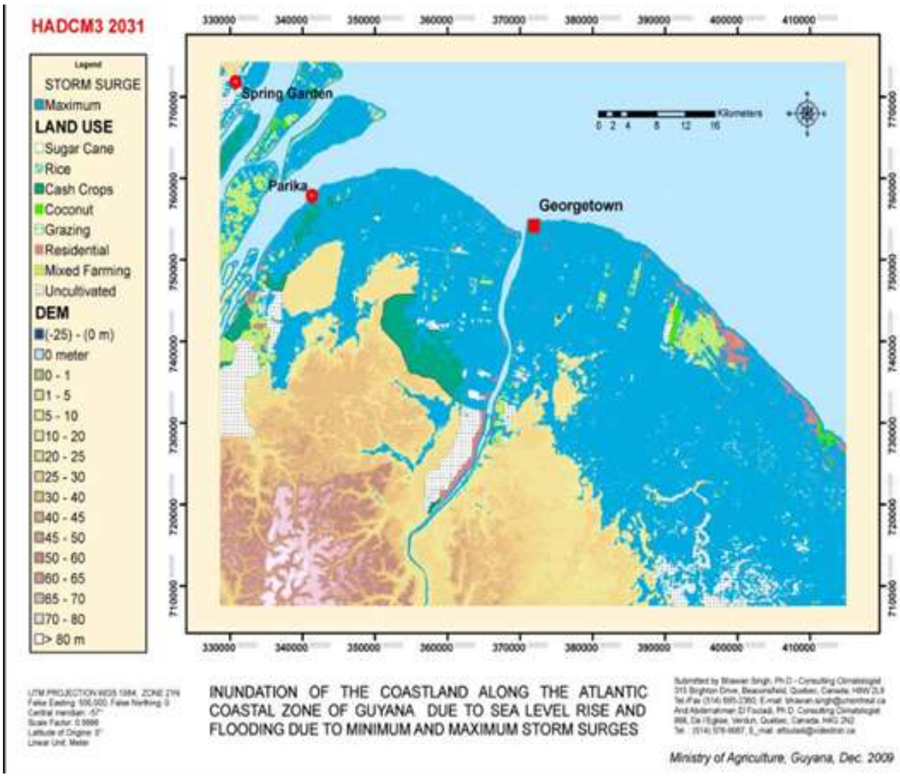


Fig. 1: Map showing the prediction of the low coastal Plain in 2031, due to sea level rise and climate change.
Source: (NLUP, 2013).

The Quinoa Crop

Taxonomy

Quinoa (Chenopodium quinoa Willd.) belongs to the group of crops known as pseudocereals. The taxonomic classification of the quinoa species is as follows: It is classified in the division Magonoliophyta, class Magnoliopsida, subclass Caryophyllidae, order Caryophyllales, family Chenopodiaceae, genusm Chenopodium, section Chenopodia and subsection Cellulata. The Chenopodium genus which has about 250 species is known to be the largest in the Chenopodiaceae family and has a worldwide distribution (Coral, et al. 2014).

Origin

Quinoa (Chenopodium quinoa Willd.) is a dicotyledonous pseudo grain which is currently being introduced as a new crop to the world (Fathi, et al., 2020). This plant is native to the Andean Highlands and was first domesticated in Lake Titicaca located along the Peruvian- Bolivian border. Its domestication began about 7000 years ago and has been used as a staple for people of the Andes (Bazile et. al., 2013). This grain was considered sacred food by the Inca civilization, and was later overlooked during the Spanish colonial period by the Spaniards who tried to replace it with other cereals (Gonzalez et al., 2019).This led to a decrease in Quinoa production in Urban areas, however cultivation on communal lands was preserved leading to the development of different types of quinoa, all having different nutritional value (Bazile et al., 2015, Bojanic, 2011) It was until the 20th century that quinoa was rediscovered, which led to the revitalization of its production. There has since been much research into the possibility of producing quinoa across the globe (Maliro et al., 2021). The quinoa seed crop has been known to endure the harsh bioclimatic conditions of the Andes since ancient times. It is mainly produced in Bolivia and Peru, however the adaptation of the crop to various conditions has led to the spread of agronomic trials and cultivation in many other countries (Ruiz, 2014).

Description

Quinoa was first botanically described in 1778 as a species of native South America (Coral et al., 2014). Quinoa is a gynomonoecious annual plant with an erect stem that bears alternate leaves. These leaves carry different colour variations ranging from green through red and purple due to the presence of betacyanins (Bhargava et al., 2005). Leaves of the plant are said to be polymorphic, with large basal leaves that are either rhomboid or triangular in shape. They are dentate and contain granules on their surfaces (Coral et al., 2014). This plant has a well-developed tap root system, penetrating as deep as 1.5 m below soil surface. This important feature enables the plant to withstand drought (Bhargava et al., 2005).The quinoa plant stands at a height of 0.5-2.0m with large panicles 1.8-2.2mm long with seeds produced at the end of the stem. This crop carries three main panicle shapes: amarantiform, glomerulate and intermediate. Panicles may be loose or compact (Rojas and Pinto, 2013). The fruit is an achene, comprising several layers, perigonium, pericarp and episperm. The seeds can have various sizes and colours ranging from yellow to white or pink. Some varieties carry seeds that are orange to red or black (Ritva et al., 2011). The Bolivian national quinoa collection identified a total of 66 grain colours (Cayoja, 1996). The grains of quinoa can be lenticular, cylindrical, ellipsoid or conical in shape with saponins concentrated in the pericarp. (Rojas and Printo, 2013; Bhargava et al., 2007). Quinoa is known to carry both hermaphrodite and unisexual female flowers (Simmonds, 1965). Inflorescence are racemose with densely populated tiny flowers which remain open for approximately 5-7 days (Mujica, 1992).

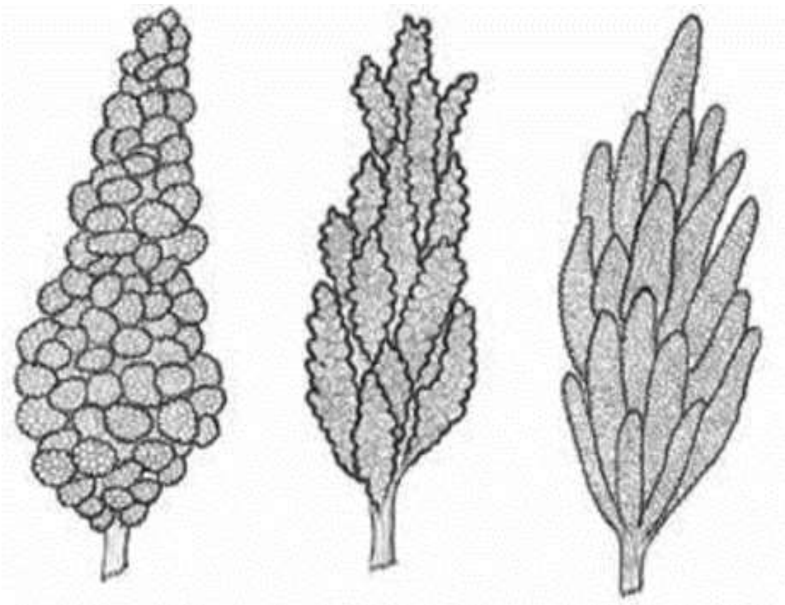


Fig: 2: Showing the three main panicle shapes of quinoa.
.1. Glomerulate, 2. Intermediate and 3. Amarantiform

Source: Biodiversity International, (Rojas and Pinto, 2013)
Uses of the crop.

Quinoa is considered to be a gluten free, highly nutritious seed crop. It can be milled ground into flour to make other edibles such as bread, muffins and tortillas or used as a cereal (Dallagnol et al., 2013). Quinoa seeds are highly digestible, as much as 80 percent digestibility and are also a rich source of protein, iron, magnesium, vitamins and fibers. The percentage of protein in quinoa seed is much higher as compared to seeds of other cereal crops including; rice, corn, and millet (Charalampopoulos et al. 2002, Bharagava et al., 2006). The quinoa grain is comparable with milk, since it is the only plant-based food that provides all essential amino acids to humans at optimum levels. The protein content of this crop ranges from 7.47 to 22.8 percent with an oil content of 1.8 to 9.5 percent, hence rich in fatty acids and also contains natural antioxidants (Bhargava et al., 2006). It therefore plays a significant role in the human diet, meeting nearly half the daily requirement for protein intake (Fathi et al., 2020). It is consumed as a whole grain without removing the bran unlike rice and wheat (Mohapatra et al., 2006). These edible seeds are also utilized as feed for animals. Quinoas gluten free nature, makes it an excellent food choice for persons with celiac disease. The leaves of this, pseudo cereal, which are treated as worthless are actually edible and may be consumed in salads and serve as additives that compliment other foods. There has been few reports on the effectiveness of quinoa saponins on agricultural pest, particularly against fungi (Coral et al. 2014) A high content of antioxidant and phenolic activity including free radical scavenging, metal chelation and lipid protection against oxidation confirms strong nutraceutical potential of quinoa, especially for the inhibition of cancer proliferation (Hirose et al., 2010).

Quinoa Crop Requirement and Management
Climate

Climate is the primary determinant of agricultural productivity (Bilalis et al., 2019). The high genetic diversity of this crop makes it possible to take advantage of its hardiness and promote its wide adaptation. Quinoa is known to thrive in a wide range of climatic conditions, including desert-like, hot, dry, cold and temperate and rainy, and hot with high humidity (Maamri et al., 2022). Quinoa can grow at relative humidity from 40% to 88%, and can resist temperatures from -4 °C to 38 °C (Coral et al., 2014). Scientific studies have confirmed that this crop can tolerate very dry conditions and drought. Quinoa is a drought-tolerant crop that is capable of growing in extremely arid environments with less than 200 mm of annual precipitation (Fuentes and Bhargava, 2011). The ideal average temperature for quinoa development and growth is around 15 °C to 20 °C, although some varieties can also withstand extreme temperatures of −8 °C to +38 °C (Bazile et al., 2015). However, this crop generally requires cool conditions for optimum growth (25-30^{0}C) (Buckland et al., 2020).

Soil

The quinoa crop can grow on a wide range of soil types including marginal soils where there is low fertility, poor drainage and high acidity or alkalinity. The crop however, thrives best on sandy loam to loamy sand soils but can also do well on black or red soils (Jacobsen, 2003, Bhargava, 2005). Quinoa can grow in a range of soils from clayey to sandy including marginal soils with a pH of 4.5–9.5. Cultivation of this crop in a new environment requires sandy loam soils with good drainage, appreciable organic matter, and nutrients (Jacobsen, 2003).

Crop management

Once seeds are set, seedlings emerge within 3-5 days, providing there is adequate moisture. Quinoa requires a seedbed with a fine tilth that is leveled and well drained for the prevention of water logging (Buckland et al., 2020). This crop can grow on high altitudes where it is impossible to grow other crops like maize, and matures within 4-7 months (Azurita- Silva et al., 2014). Seeds should be planted at a depth of half to one inch, depending on soil type. The small seed size makes it susceptible to dehydration or water logging if planted too deep or shallow. This results in poor seedling emergence (Risi et al., 1991). Studies in Malawi confirmed that quinoa establishment under rain fed conditions resulted in poor seed establishment attributed to seeds being washed away by runoff. Germinating seeds are also battered by raindrops resulting in high moisture levels, hampering germination. Quinoa seed beds which have been mulched has been proposed to improve the establishment of seedlings especially under rain fed conditions (Maliro and Guwela, 2015). Mulching has been observed to reduce or prevent seed washing down the slope as well as mechanical damage of tender seedlings. However, to prevent the seedlings from becoming spindly, the mulch should not be left too long (Maliro et al., 2021).

Commercial production of quinoa favors row spacing of about 12-18 inches apart with a dense inter-row spacing, 1 inch between plants. This arrangement facilitates the growth of a single main stem, limiting the growth of secondary stems while promoting faster maturity (Risi et al., 1991). Plant height is usually dependent on the variety of the crop planted. Each variety however is influenced by external conditions such as season, soil type, cropping density, cultivation techniques and fertilizer application rates (Wang et al., 2020).

An experiment conducted sandy loam soil was done to compare three tillage systems. The main objective of this study was to develop an automated strategy for quinoa crop management. The treatments were; one-pass using a tine cultivator followed by a roller (CD-R), one-pass using a disk harrow (CC), and no-till seeding or direct seeding (DS). Results revealed that no- till seeding system produced highest plant population, largest grain yield and highest harvest index among the treatments (Nanduri et al., 2019).

Irrigation for the quinoa crop is essential especially for the first 20-30 days. An experiment done with different types of irrigation being applied to the quinoa crop on the field concluded that the crop produced higher yields under the drip irrigation system when compared to other irrigation methods. (Ramesh et al., 2019). Quinoa does not thrive under excessive moisture conditions (Buckland, et al., 2020). Excessive irrigation in the seedling stage causes diseases like stunting and damping off. Heavy irrigation after crop stand is likely to produce tall plants with poor yields (Oelke et al., 1992). The deficit irrigation strategy has been found to be a valuable and sustainable production strategy in regions experiencing intra-seasonal dry spells (Garcia et al., 2003). This practice aims to maximize water productivity and stabilize yields rather than to increase yields (Geerts et al., 2009).

Weed management is a major factor to consider in the production of quinoa, since its control has direct impact on grain yield. Weeds are cumbersome to control; hence optimum plant density

is important to reduce weed competition (Ali et al., 2020). Attention should be given to sowing dates as the crop initially has slow growth rate after the first two weeks of emergence, as such weed competition is greater. Early sowing would therefore be advantageous since the quinoa crop can have a head start over weeds. This method of control is critical as there is absence of herbicide recommendations. Cultural weed management is very common in the production of this crop (Oelke et al., 1992).

Fertilizer requirement

Quinoa responds well to nitrogenous fertilizers. Nitrogen application is known to increase seed yield as well seed protein content (Berti et al., 2000). Heavy doses of phosphorous and potash are however known to increase vegetative growth without increasing grain yield. (Etchevers et al., 1979). It has been reported that this crop uptakes and utilizes the maximum nutrients 60-100 days after sowing. High quantities of Nitrogen, calcium and lesser amounts of potassium are absorbed (Oelke et al., 1992).

The recommended rate of nitrogen fertilization of quinoa was found by Oelke et al., (1992) to be 170–200 kg of nitrogen per hectare. Fertilizer rates exceeding this would lead to plant dormancy and delay in plant maturity. Geren (2015), found that the content of crude protein in seeds increased by 16% when fertilized at a rate of 150 kg of nitrogen per hectare and the seed yield increased to 2.95 tons per hectare. Cultivation of quinoa in Pakistan utilizes follows recommendation for nitrogen (N), phosphorus (P), and potassium (K) (N: P: K) using 75:60:50 kg ha^{-1}. A full dose of the phosphorus and potassium and 1/2 dose of nitrogen are applied to soil before or at sowing and the remaining at the flowering stage. It was reported that, high N application tended to delay maturity, increase plant height, and resulted the crop being susceptible to lodging (Basra et al. 2014). Alandia et al., 2020 discovered that increase in N rate 80–160 kg ha−1 resulted in a 10–15% rise in seed yield, while enhancing N rate up to 240 kg ha−1 resulted in negligible seed output.

Generally organic matter in the form of sheep manure (5-10 Mt/ha), goat manure (1-2Mt/ha) and chicken manure (2.5 Mt/ha) are incorporated into beds during land preparation. Nutrients such as; urea, calcium triple superphosphate and potassium chloride are also applied. Application of Nitrogen is split, usually two applications at sowing and another before flowering. (Oelke et al., 1990). Lavini et al., 2014 conducted a pot experiment using two quinoa lines (Quinoa-52 and Quinoa-37) along with two commercial varieties (Titicaca and Puno). This experiment evaluated the effect of five rates of nitrogen application (0, 50, 100,150, and 200 mg kg−1 of soil). Results showed that both lines responded comparably to the application of nitrogen with notable increase in yield with increased nitrogen rates. Choukr-Allah et al., 2016 conducted research focusing mainly on testing various nitrogen does (0, 40, 80, 120, 160, 200, and 240 Kg ha−1) under four irrigation regimes (25, 50, 75, and 100% of full irrigation). Results revealed that seed yield increased with increasing nitrogen supply. The response however varied as the changes in the levels of water stress.

Adaptability of the Quinoa Crop

Crop tolerance

An understanding of the physiological and structural mechanisms that determine tolerance in quinoa is a necessary for its sustainable utilization as a crop (Jacobsen 2011). The quinoa crop has been admired for its ability to maintain productivity under a wide range of stressors and marginal soils, as such it is promoted as both a nutritious and efficient crop for, low input cropping systems or harsh environments (Hinojosa et al., 2018). Quinoa can tolerate a wide range of soil pH from 4.8 to 9.5, mainly attributed to mycorrhizal associations, thus maximizing the use of limited nutrients (Bermejo, 1994). This plant tolerates poor and rough environments and has great adaptability to various agro-climatic conditions and can tolerate drought, frost, heat, salinity and poor soil in comparison with other crops (Carmen, 1984; Martinez et al., 2009). Genetic diversity of quinoa has made it possible to cultivate this crop successfully on different types of soils, particularly saline soils where environments may have extremely variable conditions in terms of humidity altitude and temperature. The ability for quinoa to produce quality yields under low fertility depends largely on the cultivar (Wieme et al. 2020).

The adaptability and hardiness of this crop makes it an alternative crop to be grown worldwide in the face of climate change and large-scale salinization of agricultural lands (Ruiz et al., 2013). There is a wide variation on salt tolerance in quinoa (Bendevis et al. 2014). Studies have been carried out to evaluate quinoa responses to salinity. These proved that quinoa as a halophyte tolerates high levels of salinity and can also thrive under sea water salinity (Adolf et al. 2012). Adaptation to saline conditions is attributed to its ability to accumulate salt ions in its plant tissue, resulting in the adjustment of leaf water potential thus enabling the plant to maintain turgor and enables decreased transpiration under saline conditions (Jacobsen et al., 2001).

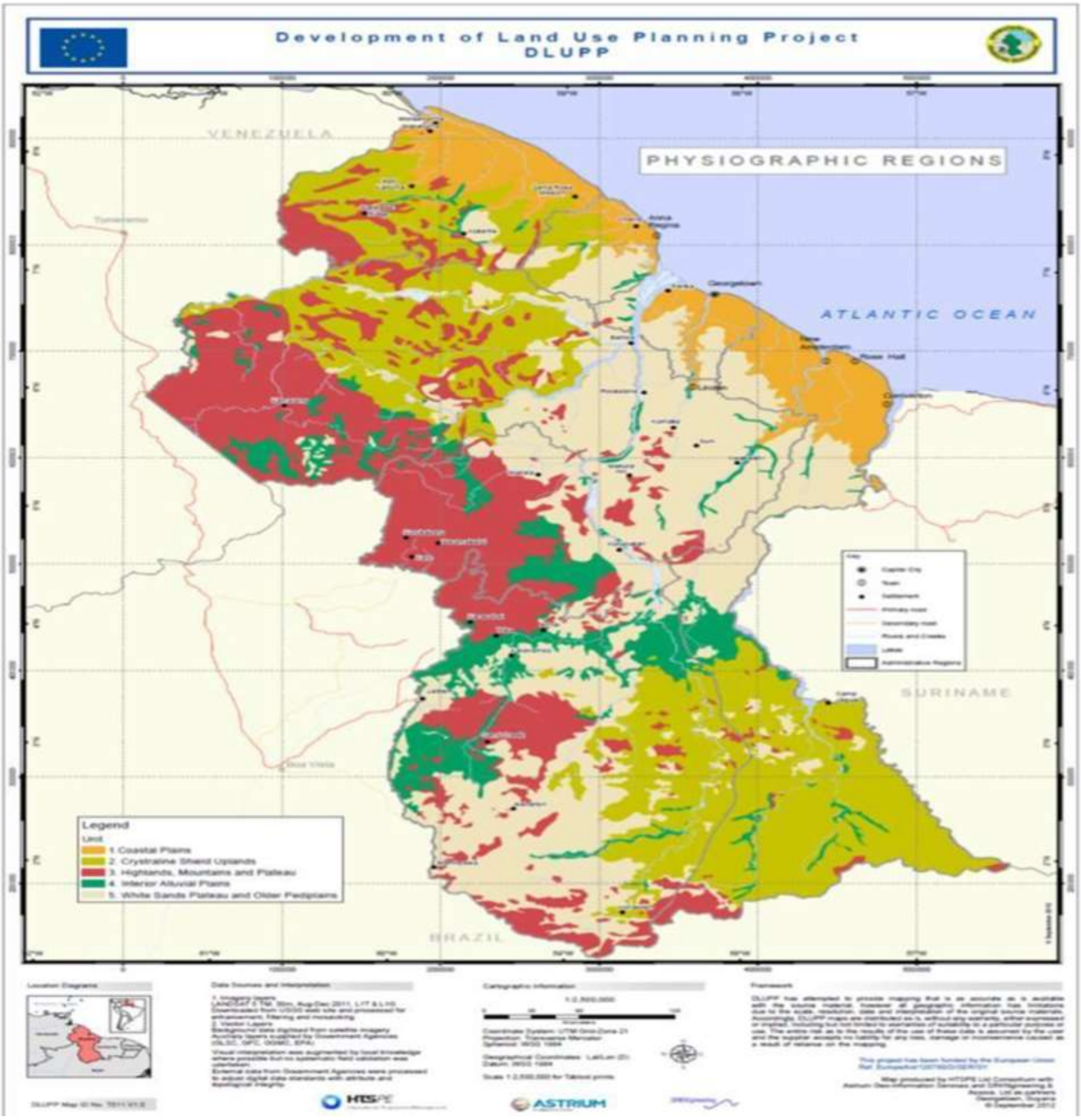
The response of this crop to high temperatures and other abiotic stresses varies depending on the cultivar as well as the combination of stressors at any given time. Some cultivars can have increased height, biomass or yield with increased temperatures. On the other hand, high temperature combined with low water availability can result in significant yield losses (Bazile et al., 2016; Hinojosa et al., 2018; Wieme et al., 2020).

This crop has the extraordinary ability to survive under conditions of low water supply. Based on its inherent low water requirement and ability to quickly resume its photosynthetic level after a period of drought (Jacobsen et al., 2003). Mechanisms related to drought resistance present in quinoa, include; drought escape, tolerance, and avoidance. These however depend significantly on varietal differences (Jensen et al., 2000). Quinoa tolerates drought through growth plasticity, tissue elasticity, and low osmotic potential. The plant also avoids the negative effects of drought

through reduction of leaf area, dropping of leaves; special vesicular glands; small and thick-walled cells, adapted to large losses of water without loss of turgor and stomatal behavior (Jensen et al., 2000). This makes quinoa suitable for growing in arid and semi- arid regions where farmers depend heavily on rainfall for irrigation. Morphological characters of quinoa such as a ramified tap root system with hydroscopic calcium oxalate also supports drought resistance of this crop (Bhargava et al., 2005).

Resistance to pest and diseases

The quinoa crop is infected by a number of pathogens which cause diseases like damping off, mildews, blight and mosaic. Although viruses are known affect the plant, reports of significant effects are yet to be reported. Downy mildew caused by the fungus *Peronospora farinosa* is the most damaging disease of quinoa (Danielsen et al., 2003). The disease has been reported from all areas of quinoa cultivation including Bolivia, Peru Ecuador and Colombia. In the Andean highlands, it is considered an endemic. Downy mildew disease is the most severe affecting quinoa production which causes devastating yield losses of up to 30 −50% in tolerant cultivars, and an almost complete yield loss in susceptible cultivars under conditions of high humidity and absence of chemical control measures (Danielsen et al., 2000; Danielsen et al., 2004). Genetically improved varieties with reliable resistance to this disease are still unavailable, however observations have been made regarding differences in susceptibility among cultivars. A study in Peru, 1976 described genotypes as resistant or moderately resistant at flowering or fructification stages (Otazu et al. 1976). Quinoa is not susceptible to cereal diseases and tolerant to most soil-borne nematodes (Jacobsen, 2003). It was discovered that resistance to downy mildew is found in wild species that are associated with the cultivated crop. These species harbor the downy mildew resistant gene. These sources may be useful for creating commercial resistant varieties through hybridization techniques (Danielsen et al., 2003). The most common pest affecting quinoa are birds which attack quinoa at the inflorescence stage. These however cause only minor damage and does not affect yields. This plant has chemical defence in the form of saponins that confer resistance against pest (Risi and Galwey, 1984). Quinoa varieties however differ in their saponins content hence causing some varieties to offer better resistance than others (Ya´bar et al., 2001).



Guyana's Physiographic Regions
Fig. 3: Shows Guyana's five physiographic regions.
Source: (NLUP, 2013).

The tropical country, Guyana is located on the Northeastern coast of South America. The country lies between 2°N and 8°N Latitude and 57°W and 61.5°W Longitude and has a total land area of 214,970 square kilometers (UNFCCC 2012). Guyana has a tropical climate distinguished by a high but variable rainfall, high humidity and a relatively small temperature range with two wet and two dry seasons (NLUP 2013). Guyana is mapped into five physiographic regions namely, the (i) Low Coastal Plain (ii) The Interior Alluvial Plains and Low-Lying Lands (iii) White Sand Plateau (iv) Crystalline Shield Uplands (v) Highlands, mountains and Plateau (FAO, 1966).

Coastal plain

The Coastal Plain can be described as a narrow belt stretching from the Corentyne River in the east to Waini Point in the west. The Coastal Plain is known to have a soil type of clays and silts occurring on the coast while silty clays and sands occur inland. The plain is composed of a soil developed from a variety of parent materials such as marine and fluvio-marine deposits with back-swamp organic soils. In general, it was found that soils closer to the shore and along rivers are more fertile than the soils further away which have very low fertility and, in some cases, high toxicity. Some areas on the coastline lies just 2 meters below sea level causing flooding to be imminent (NLUP 2013).

Hilly sand and clay region.

The Hilly Sand and Clay Region, known as the white Sand Plateau is found just inland of the coastal zone. This region is undulating with altitudes of 15m above sea level close to the coast and altitudes of 150m in the southern most parts. This region is dominated by soils that are white and brown in nature that have laterite gravel and bauxite. White sand soils are highly permeable and are deficient in nutrients (NLUP, 2013). The application of organic materials as ameliorants to soil can increase soil aggregate stability, soil permeability and soil cation exchange capacity (CEC) (Haryati et. al, 2021). Restoration of soil properties can be done using various materials for amelioration, one such material is biochar. Biochar is described as the solid, carbon rich material obtained by pyrolysis using various biomasses (Rawat, 2019). It was found that a positive effect of biochar on the soil properties is manifested through the improvement of soil fertility, better water retention, improvement of the cation exchange, and the regulation of the pH (Scislowska et al., 2015). Compared with other soil ameliorants, biochar also has the ability to remain stable in soil, it can survive in the soil for a long time and function as carbon conservation and as a good habitat for microorganisms (Haryati et al., 2021). In arid and semi-arid regions, calcareous sandy soils suffer from nutrient deficiency as a result of low organic matter, content and consequently poor structure. It has been demonstrated that biochar can act as a slow-release source of nutrients, and can provide macronutrients and improve soil physico-chemical properties (Rekaby et al., 2021). The addition of biochar to sandy soil changes soil characteristics such as its structure and porosity (Kammann et al., 2011).

Highland, mountains and Plateaus.

Highlands, mountains and plateaus comprise of the boarder of Brazil and Venezuela. This region is said to be located north of the Amazon and South of the Orinoco River. This area is distinguished by the presence of igneous and metamorphic mountains that are densely forested and remains virtually inaccessible. The soils in this region are variable consisting of deep and shallow soils. Deep soils are developed from basic igneous rocks that are generally well drained and varies in levels of fertility (lNLUP, 2013).

Crystalline Shield Uplands

The Crystalline Shield Uplands occur in the north-west and south-east of Guyana and is part of the larger Guiana Peneplain. The unit is described as a monotonous continually rolling to hilly land, dominantly forested. The area is generally flat although some areas have undulating topography. The soils have developed from igneous and metamorphic rocks and are generally well drained, of variable depth and are largely of low fertility with a high erosion hazard if the cover were to be removed (NLUP, 2013).

Interior Alluvial plains.

The Interior Alluvial Plains and other low-lying lands dominate extensive parts of the interior and are most extensive in the Rupununi savannas both south and north of the Kanuku Mountains. This area is dominated by grasslands and short trees and shrubs as vegetation. Soils in this region are derived from alluvium and are generally hydromorphic with poor drainage and are known to have low fertility (NLUP, 2013)

Quinoa: Distribution, Economic importance and World Production trends.

The launching of field trials in the United Kingdom, Denmark, Italy, Netherlands, Scotland and France begun in 1966 through the DANIDA (Danish International development agency) and the CIP (International Potato Center) in Peru. These international trials played a major role in enabling the global expansion of quinoa. Trials were later set up in other countries like Poland, Sweden, Germany and Austria, who participated in American and European tests of Quinoa organized by the FAO. These projects aimed at strengthening research of the crop through experimentation at an international level (Bazile, et al. 2015).

Cultivation of quinoa is indigenous to the South American Andes region, from Colombia to Argentina and Chile (Gonzalez et. al., 2015; FAO, 2013). Adaptability of quinoa to various agro-climatic habitats and edaphic conditions has overtime increased the yields of different varieties in countries outside South America, such as Europe, USA, Canada, China, and India (Gonzalez et al., 2012). In the global distribution of quinoa the primary producers of quinoa production are Peru and Bolivia. Other countries that produce this crop mostly for local consumption are USA, Ecuador, and Chile, Canada, Colombia, Argentina, and Mexico (FAO, 2011). Quinoa known as "the golden grain of the Andes" has Bolivia, Peru, and Ecuador remaining the major quinoa-producing and exporting countries in the world. Bolivia and Peru jointly produce the world's majority of quinoa, about 80%. The remaining 20% production comes from Ecuador, USA, China, Chile, Argentina, France and Canada (Bazile et al., 2016).

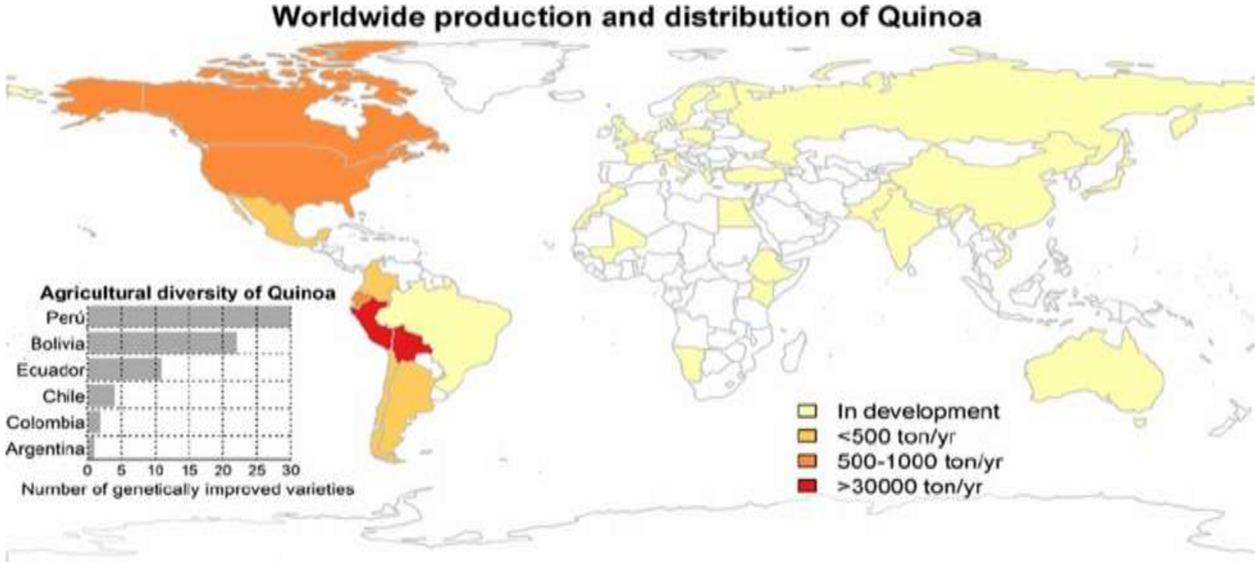


Fig. 4: Distribution of Quinoa. Source: Ahmadzai, et al., 2020.

Quinoa has been perceived as a climate resilient crop of great value; as such there has been significant attempts, for its introduction in various marginal agriculture production systems across the globe (Jacobsen et al., 2003). Quinoa has tremendous potential to contribute to food security because of its nutritional quality, genetic variability, adaptability to adverse climate, soil conditions, and low production cost. The introduction of high yielding domestically grown quinoa in developing countries not only gives scope for ensuring nutritional security, but also gives promise for export opportunities as the demand for this crop grows in the developed world
(Maliro et al., 2019). Cultivation of quinoa provides an alternative for countries with inadequate food production. Establishment of this crop would therefore aid in eliminating food imports and eradicating the need for food aid. (FAO, 2011). Its exceptional ability to grow in marginal environments coupled with its high nutritional quality has led to the Food and Agriculture Organization of the United Nations (FAO), to recognize this crop as one that would play an important role in ensuring future food security (Bazile et al., 2015).

The increase in the global production and research of the crop over the past decades has led to the Food and Agricultural Organization declaring the year 2013 as the international year of quinoa (FAO, 2013). Quinoa is widely used in many South American countries including; Peru, Bolivia, Ecuador, Chile, and Argentina. The people of these countries are conscious of the nutritive quality of this crop and consume quinoa at least once per day utilizing different methods of preparation (Ayaia, 2003). The seeds may be eaten as a rice replacement or as a breakfast cereal (Bhargava et al., 2006) There are several products derived from quinoa, such as puffs, flour, pastas, flakes, granola, energy bars, among others (FAO, 2011). Apart from being used for human consumption, quinoa seed can also be used for livestock and poultry feed. The whole plant can be used as green fodder and harvest residues can be fed to the animals (Choukr- Allah, et al. 2016). The use of quinoa as feed for animals however depends largely on the amount of residue. The biomass of this crop can be utilized as fodder in areas where other crops cannot grow at elevated altitudes. The quinoa husk and seed bran are potential sources of feed for domesticated animals. It also has the potential to be an alternative source of energy when utilized as a substitute for conventional fuels in rural areas in the form of pellets (Angeli et al., 2020). The seeds of quinoa have higher nutritive value than cereal grains with notable protein contents and large quantities of carbohydrates, fats and minerals. Some products requiring the use of advanced technologies are also being explored, such as the extraction of quinoa oil, starch, saponin, colourings from the leaves and seeds as well as protein concentrates (FAO, 2011). Milk, another nutritive product of quinoa is suitable for those who are unable to digest casein or animal lactose, while its oil is high in natural antioxidant content. Quinoa is a good source of thiamine, folic acid and vitamin C. The seeds contain higher amounts of Ca, P, Mg, Fe, Na, and Cu than Cereals (Singh et al., 2021). Quinoa seeds and leaves can be used to produce alcohol, anti-inflammatory drugs, disinfectants and insect repellents (Vega-Gálvez et al., 2010). These products are regarded to be the economic potential of quinoa, since they contribute to its nutritional and its physicochemical characteristics. The economic benefits of this crop reach beyond the food industry, offering products to the chemical, cosmetic and pharmaceutical industries. (FAO, 2011).

The FAO identified quinoa as a crop that could ensure food security since in the 1940's, as such campaigned to increase consumption in three Andian countries. The increase in consumption however, did not come about until the 1980's, when high income countries became interested in the crop. (Andrango, et al., 2020)

The rapid global expansion of Quinoa has led to it going from an obscure food product to a highly demanded internationally traded product, attributed to the growing numbers of new international producers (Scanlin and Lewis, 2017). Although this crop is known to be originated in the Andean Regions, research has led to the development and promotion of germ plasm trials in non-traditional areas of cultivation, resulting in growing interest among countries for production. The number of countries growing the crop has increased rapidly from eight in 1980, to 40 in 2010, and to 75 in 2014. An additional 20 countries have sown quinoa for the first time in 2015 (Bazile et al., 2016). Quinoa is currently being tested or cultivated in over 95 countries around the world (Bazile, 2015).

The 1970's recorded national production of quinoa to be approximately 9,000 metric tons per year, covering a surface area of approximately 12,000 cultivated hectares. This has increase significantly in recent years to an average of 22,000 metric tons per year, utilizing 35,000 hectares of land (PROINPA foundation, 2004). Yields recorded globally from 2007 to 2014 proved that there were significant increases in productivity during this period, with yield improvements in Peru being doubled from 0.97 to 1.93 t/ha. Various regions around the world reported yield increases of over 3.92 t/ha, indicating improvements in technology and the introduction of high yielding varieties (Jacobsen, 2003; Scanlin and Lewis, 2017). Bolivia and Peru were the two leading producing countries in 2017 for international export of Quinoa. The market share was occupied predominantly by these countries, Bolivia 57% and Peru 37%, with minor contributions from the USA, 2.5% and Canada 2%. Other countries contributed about 3.5% quinoa to the international market (Ahmadzai, 2020). In terms of imports, the United States and Canada are the most popular destinations. The USA accounted for 40% of global demand, followed by Europe 32% and Canada 11%, with less than 20% demanded by the rest of the world, including Germany, Holland, France and Japan (Ahmadzai, 2020). Although quinoa is a traditional food in South America, the U.S. is by far the largest importer of quinoa worldwide for use as a rice or grain (FAOSTAT, 2020). Massive importation of this product has also been attributed to the large-scale manufacturing of products that contain quinoa in the U.S. This has caused top producing Andean countries to drastically intensify production to satisfy global demands (Buckland et al., 2020).

The major importers of quinoa in 2019 is shown in figure 5. The United States imported 30% of the total world imports while the European Union imported 43%. Other important importers were Canada (8%), Australia (3%), Chile (3%), and Brazil (2%). Russia, Japan, the United Arab Emirates, Argentina, and New Zealand together accounted for the remaining 9% of imports of quinoa (ITC, 2020).

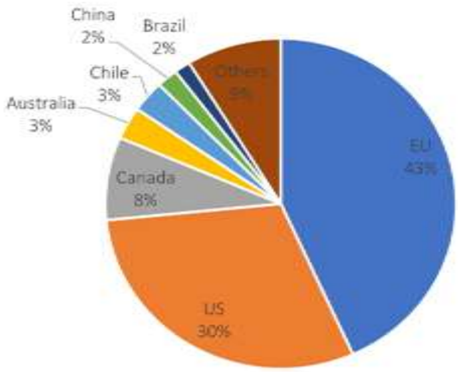


Fig. 5: Major importers of quinoa in 2019
Source: ITC, 2020

Worldwide trends for quinoa production for the 2010 – 2021 period suggest that global production in 2017 amounted to over 146 thousand metric tons. There was a subsequent increase in the following three years, with production increasing to more than 175 thousand metric tons before a decline in 2021 with production being about 147 thousand metric tons (Shahbandeh, 2023).

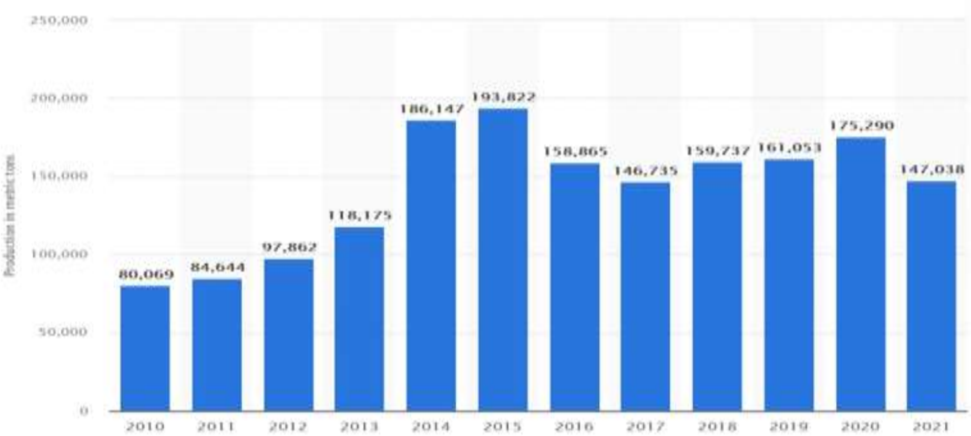


Fig. 6: Worldwide trends for Quinoa Production 2010-2021. Source: Shahbandeh, 2023

The quinoa crop prices have tripled between 2006 and early 2013. In 2011 the average crop value was about 3115 USD per ton. Some varieties were sold for prices as high as 8000 per ton (Ruiz et al. 2014). The global average price of quinoa rose substantially between 2012 and 2014, from 3.21 to 6.74 USD per kilogram. In December, 2021 a kilogram of quinoa costed about 1.64 USD on average worldwide (Shahbandeh, 2023)

As the worldwide demand for quinoa along with total international imports caused significant price increases throughout the 1990's towards the year 2016. Figure 7 shows the relationship between prices received by Andean quinoa producers and total world imports. Prices remained stable during the 1990s and early 2000s. However, between 1991 and 2007, quinoa prices increased by only 7.81% in Bolivia and 20.52% in Peru. In 2008 to 2014, prices sharply increased by 304.75% in Bolivia and 407% in Peru. Imports continued on the increasing trend in 2012 to 2016. (ITC, 2020)

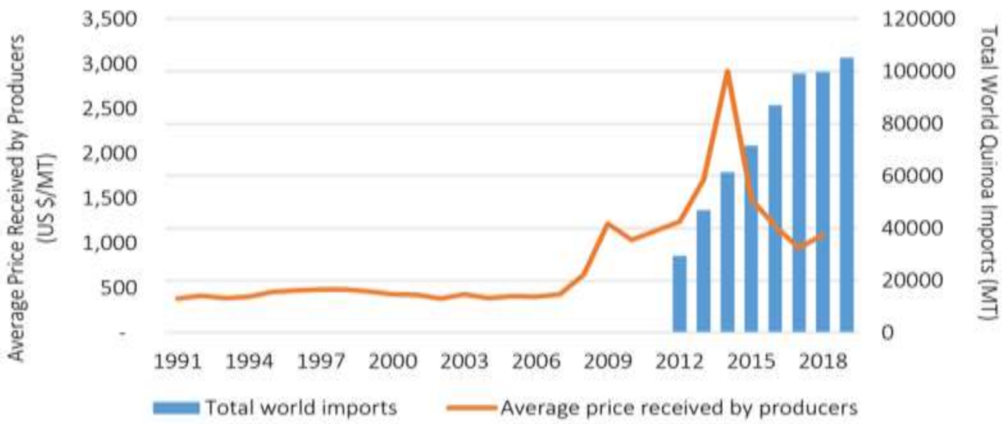


Fig. 7: Relationship between prices received by Andean quinoa producers and total world imports. Source: (ITC, 2020)

Conclusion

It can be concluded that:

1. Alternative land located away from the coastline must be considered for future crop establishment.
2. Soil amelioration may be necessary for the successful production of quinoa on problematic and nutrient deficient soils.

The current worldwide production trends of Quinoa, has proven that there are large scale international markets available for export opportunities for Guyana once this crop can be successfully established. Therefore, the quinoa crop may have the potential to ensure food security, creating crop diversity and economic gains for Guyana.

References

1. Adolf, V., Shabala, S., Andersen, M. Razzaghi, F. & Jacobsen, S. (2012). Varietal differences of quinoa's tolerance to saline conditions. Plant Soil **357**, 117–129 (2012). https://doi.org/10.1007/s11104-012-1133-7
2. Aguilar, P., Cutipa, Z, Machaca, E., Lopez, M., & Jacobsen, S.E (2003). Variation of proline content of quinoa (Chenopodium quinoa Willd.) in high beds (Waru waru). Food Rev Int. 19: 121–127., DOI: 10.1081/FRI-120018878
3. Ahmadzai, H. (2020). Trends in Quinoa Adoption in Marginal Areas: An Assessment of Economic Viability and Policy Outlook. Journal Agri- business Rural Development. 3(57), 235–247. http://dx.doi.org/10.17306/J.JARD.2020.01351
4. Alandia, G., Rodriguez, J., Jacobsen, S., Bazile, D. & Condori, B. (2020) Global expansion of quinoa and challenges for the Andean region. Global food Security. (26)10049 http://doi.org/10.1016/j.gfs.2020.100429.
5. Ali, S., Chattha, M., Hassan, M., Khan, I., Chattha, M., Iqbal, B., Rehman, M., Nawaz, M. & Amin, M.Z. (2020) Growth, biomass production, and yield potential of quinoa (Chenopodium quinoa Willd.) as affected by planting techniques under irrigated conditions. International Journal of Plant Production. 14 (12) DOI: 10.1007/s42106-020-00094-5
6. Andrango, G., Johnson, A. & Bellemare, M. (2020). "Quinoa Production and Growth Potential in Bolivia, Ecuador, and Peru" Choices. Quarter 4. Available online: https://www.choicesmagazine.org/choices-magazine/theme-articles/functional-foods-fad-or-path-to-prosperity/quinoa-production-and-growth-potential-in-bolivia-ecuador-and-peru.
7. Angeli, V., Silva P., Massuela D., Khan M., Hamar, A., Khajehei, F., Graeff-Hönninger, S., & Piatti, C. (2020). Quinoa (Chenopodium quinoa Willd.): An Overview of the Potentials of the "Golden Grain" and Socio-Economic and Environmental Aspects of Its Cultivation and Marketization. Article in Foods (9)2. DOI:10.3390/foods9020216.
8. Ayaia, G. (2003). Consumption of quinoa in Peru. Food Reviews International, 19:1-2, 221-227, DOI: 10.1081/FRI-120018887.
9. Azurita-silva, A., Jacobsen, S., Razzaghi, F., Alvarez-flores, R., Ruiz, K., Morales, A., & Silva, H. (2014). Quinoa drought response and adaptation. In: State of the art of quinoa around the world in 2013, FAO.
10. Baker, A., Ceasar, S., Palmer, A., Paterson, J., Qi, W., Muench, S. & Baldwin, S. (2015) Replace, Reuse, recycle: Improving the Sustainable Use of Phosphorus by Plants. Journal of Exp. Botany, 66, 3523–3540. https://doi.org/10.1093/jxb/erv210
11. Basra, S., Iqbal, S. & Afzal, I. (2014) Evaluating the response of nitrogen application on growth development and yield of quinoa genotypes. International Journal of Agriculture Biology. 16(5):886–892.
12. Bazile, D. & Baudon, F. (2015). The dynamics of the global expansion of quinoa growing in view of its high biodiversity. In: Bazile, D., Bertero, D. &Nieto, C. State of the Art Report of Quinoa in the World in 2013. FAO & CIRAD: pp. 42–55. Available online: http://www.fao.org/3/a-i4042e.pdf.
13. Bazile, D., Bertero, H. & Nieto, C. (2015) State of the Art Report on Quinoa around the World in 2013. FAO & CIRAD: p. 603. http://www.fao.org/3/a-i4042e.pdf.
14. Bazile, D., Jacobsen, S., & Verniau, A. (2016). The global expansion of quinoa: Trends and Limits (Mini Review) Frontiers in Plant Science. (7) 622. https://doi:103389/fpls.2016.00622.
15. Bazile, D., Martínez, E., Fuentes, F., Chia, E., Namdar-Irani, M., Olguín, P., Saa, C., Thomet, M. & Vidal, A. (2015). In: Bazile, D., Bertero, D., Nieto, C. Quinoa in Chile. In State-of-the-Art Report of Quinoa in the World in 2013; FAO & CIRAD: pp. 401–421, Available online: http://www.fao.org/3/a-i4042e.pdf.
16. Bazile, D.; Fuentes, F.; Mujica, A. (2013) Historical perspectives and domestication. In: Bhargava, A. & Srivastava, S. Quinoa: Botany, Production and Uses. CABI: Wallingford, UK, pp. 16–35
17. Bendevis, M., Sun, Y., Shabala, S. Rosenqvist, E., Liu, F. & Jacobsen, S. (2014). Differentiation of photoperiod-induced ABA and soluble sugar responses of two quinoa (Chenopodium quinoa Willd.) cultivars. Journal of Plant Growth Regulation 33:562–570, https://doi.org/10.1007/s00344-013-9406-9. Bhargava A, Sudhir S, Deepak Ohri. (2006) Quinoa (Chenopodium quinoa Willd.). An Indian perspective. Industrial crops and products. 23:73-87.2 https://doi.org/10.1016/j.indcrop.2005.04.002.
18. Bermejo, H. & Leon, J., (1994). Neglected crops: 1492 from a different perspective. FAO Plant Production and Protection (Series No.26), FAO.
19. Bilalis, D., Roussis, I., Kakabouki, I. and Folina, A. (2019). Quinoa (Chenopodium quinoaWilld.) crop under Mediterranean conditions: A Review. Cien. Inv. Agr. 46(2): 51-68. DOI 10.7764/rcia.v46i2.2151
20. Bojanic, A. (2011) Quinoa: An Ancient Crop to Contribute to World Food Security; (pp. 1-39) FAO, http://www.fao.org/3/aq287e/aq287e.pdf.
21. Bouwman, A., Beusen, A., Lassaletta, L. Van Apeldooran, D., Van Grinsven, H., Zang, J. & lttersum Van, K. (2017). Lessons from temporal and spatial patterns in global use of N and P fertilizer on cropland. Scientific Reports **7(1)**, 40366. https://doi.org/10.1038/srep40366
22. Cayoja, M. (1996). Caracterización de variables contínuas ydiscretas del grano de quinua (Chenopodium quinoa Willd.) del banco de

germoplasma de la Estación Experimental Pata-camaya. Oruro, Bolivia, Universidad Técnica Oruro, Facultad de Agronomía. p. 129

23. Charalampopoulos, D., Wang, R., Pandiella, S., Webb, C. (2002). Application of cereals and cereal components in functional foods: a review. Int Jour Food Microbiol. 15; 79(1-2):131-41. doi: 10.1016/s0168-1605(02)00187-3.
24. Choukr-Allah R, Rao NK, Hirich A, Shahid M, Alshankiti A, Toderich K, Gill S and Butt KUR (2016) Quinoa for Marginal Environments: Toward Future Food and Nutritional Security in MENA and Central Asia Regions. Front. Plant Sci. 7:346. doi: 10.3389/fpls.2016.00346
25. Coral, L. & Cusimamani, E (2014). An Andean Ancient Crop, Chenopodium quinoa Willd. A Review. Crop sciences and Agro- forestry 47(4): 142-146 DOI: 10.2478/ats-2014-0020.
26. Dahlawi, S., Naeem, A., Rengel, Z. & Ravi, N. (2018). Biochar application for the remediation of salt-affected soils: Challenges and opportunities. Science Total Environment. 1; 625:320-335. DOI: 10.1016/j.scitotenv.2017.12.257.
27. Dallagnol, A., Pescuma, M., De Valdez G., Rollán, G. (2013). Fermentation of quinoa and wheat slurries by Lactobacillus plantarum CRL 778: proteolytic activity. Appl Microbiol Biotechnol. 97(7):3129-40. doi: 10.1007/s00253-012-4520-3.
28. Danielsen, S. & Munk L., (2004). Evaluation of disease assessment methods in quinoa for their ability to predict yield loss caused by downy mildew. Crop Protection 23:219–28.DOI: 10.1016/j.cropro.2003.08.010.
29. Danielsen, S., Alejandro, B., &Teresa, A., (2003). Diseases of Quinoa (Chenopodium quinoa). Food Reviews International, 19:1, 43 – 59. DOI: 10.1081/FRI-120018867.
30. Danielsen, S., Jacobsen, S., Echegaray, J., Ames, T., (2001). Impact of downy mildew on the yield of quinoa. In: CIP program report 1999–2000. International Potato Center, Lima, Peru, pp.397–401.
31. Ding, Z., Zhou, Z., Lin, X., Zhao, F.,Wang, B., Lin, F., Ge, Y. & Eissa, M. (2020). Biochar impacts on NH3-volatilization kinetics and growth of sweet basil (Ocimum basilicum L.) under saline conditions. Industrial Crops and Products.157- 159. DOI: 10.1016/j.indcrop.2020.112903.
32. Eswar, D., Rajan, K. & Chellamuthu, S. (2020). Drivers of Soil Salinity and their Correlation with Climate Change. Current opinion in environmental sustainability (50) DOI: 10.1016/j.cosust.2020.10.015.
33. Etchevers, B., Avila, T. (1979). Factores que afectan el crecimiento de quinua (Chenopodium quinoa) en al centro-sur de Chile. Pap. 10th Lat. Am. Meet. Agric. Sci. 14: 13-29
34. FAO (2011). The state of food insecurity in the world. Food and Agriculture Organization of the United Nations,Rome. http//: www.fao.org/docrep/014/i2330e/i2330e.pdf.
35. FAO (2013), FAOSTAT. The state of food and agriculture. Food systems for better nutrition. Food and Agriculture Organization of the United Nations http://faostat.fao.org/default.aspx
36. FAOSTAT, (2020) Food and Agriculture Organization of the United States Crops and Livestock
37. Fathi, A. & Kardoni, F. (2020). The importance of quinoa (Quinoa Chenopodium willd) cultivation in developing countries: A review. Journal of App. life Sciences and Env.3 (183): 337-356. DOI: 10.46909/cerce-2020-030
38. Fuentes, F., & Bhargava, A. (2011). Morphological analysis of quinoa germplasm grown under low-land desert conditions. Journal of Agronomy and Crop Science. 197:124–134. https://doi.org/10.1111/j.1439-037X.2010.00445.x
39. Garcia, M. (2003). Agroclimatic study and drought resistance analysis of Quinoa for an irrigation strategy in the Bolivian Altiplano. In: Ph.D. dissertation. Faculty. of Agr. and Applied Biol. Sciences. Online access: http://www.secheresse.info/spip.php?article13129
40. Garcia, M., Raes, D., & Jacobsen, S. (2003). Evapotranspiration analysis and irrigation requirements of quinoa (Chenopodium quinoa) in the Bolivian highlands. Agriculture Water Management. 60, 119–134. DOI: 10.1016/S0378-3774(02)00162-2.
41. Geerts, S., & Raes, D. (2009). Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agriculture Water Management. 96(9): 1275–1284. DOI: 10.1016/j.agwat.2009.04.009
42. Geren, H. (2015). Effects of different nitrogen levels on the seed yield and some yield components of quinoa (Chenopodium quinoa Willd.). Turk J Field Crops. 20(1): 59-64 DOI:10.17557/.39586.
43. González, A., Eisa, S. Hussin, .S & Prado, E. (2015). Quinoa: An Incan Crop to Face Global Changes in Agriculture. In: Murphy, K., Matanguihan, J., Eds.; Quinoa: Improvement and Sustainable Production; John Wiley & Sons inc, doi: 10.1002/9781118628041.ch1.
44. González, J., Eisa, S., Hussin, S. & Prado, F.(2015) Quinoa: An Incan Crop to Face Global Changes in Agriculture. (2015) Institute of Ecology 1-18. DOI: 10.1002/9781118628041.ch1.
45. González, J., Konishi, Y., Bruno, M.,Valoy, M. & Prado, F. (2012). Interrelationships among seed yield, total protein and amino acid composition of ten quinoa (Chenopodium quinoa) cultivars from two different agroecological regions. Journal Science Food Agriculture.92 (6): 1222-1229, DOI: 10.1002/jsfa.4686.
46. Government of Guyana (UNFCC) United Nations Framework Convention on Climate Change. (2012). Guyana Second National Communication to the UNFCCC. https://unfccc.int/resource/docs/natc/guync2.pdf.
47. Guyana Climate Change Action Plan (2001). In response to its commitments to the UNFCCC. Actions for addressing climate change. Online access: https://unfccc.int/resource/docs/nap/guynap01.pdf.
48. Guyana land and Surveys Commission (2013). Guyana National Land Use Plan 2013. Online access: https://glsc.gov.gy/wp-content/uploads/2017/05/National-Land-Use-Plan-Final-Oct-2013.pdf.
49. Haryati, U., Maswar & Irawan (2021). Application of

mulch and soil ameliorant for increasing soil productivity and its financial analysis on shallots farming in the upland. Earth and Environmental Science 648, DOI: 10.1088/1755-1315/648/1/012155.
50. Hasegawa P.M (2013) Sodium (Na+) homeostasis and salt tolerance of plants. Environmental Experimental Botany.92:19–3. DOI: 10.1016/j.envexpbot.2013.03.001
51. Hinojosa, L., González, J., Barrios-Masias, F., Fuentes, F. & Murphy, K. (2018). Quinoa Abiotic stress responses. A review. Plants, 7(4), 106; https://doi.org/10.3390/plants7040106
52. Hirose, Y., Fujita, T., Ishii, T., Ueno, N. (2010). Antioxidative properties and flavonoid composition of Chenopodium quinoa seeds cultivated in Japan. Food Chemistry 119:1300-1306. https://doi.org/10.1016/j.foodchem.2009.09.008.
53. International Trade Center (ITC). 2020. "List of Exporters for the Selected Product. Product: 100850 Quinoa "Chenopodium quinoa.'" Trade Map. Available online: https://www.trademap.org/Country_SelProduct_TS.aspx?nvpm=1%7c%7c%7c%7c%7c100850%7c%7c%7c6%7c1%7c1%7c2%7c2%7c1%7c2%7c2%7c1%7c1
54. International Trade Center (ITC). 2020. "List of Exporters for the Selected Product. Product: 100850 Quinoa "Chenopodium quinoa.'" Trade Map. Available online: https://www.trademap.org/Country_SelProduct_TS.aspx?nvpm=1%7c%7c%7c%7c%7c100850%7c%7c%7c6%7c1%7c1%7c2%7c2%7c1%7c2%7c2%7c1%7c1.
55. Jacobsen S-E. and Mujica, A. (2006). The worldwide potential for quinoa (Chenopodium quinoa Willd.). Food Reviews Int. 19:167-177. Doi: http://dx.doi.org/10.1081/FRI-120018883
56. Jacobsen, S-E, (2011). The situation for quinoa and its production in Southern Bolivia: from economic success to environmental disaster. Agronomy Crop Science. 197 (5): 390–399, DOI:10.1111/j.1439-037X.2011. 00475.x
57. Jacobsen, S-E, Mujica, A. & Jensen, C. (2003). The Resistance of Quinoa (Chenopodium quinoa Willd.) to adverse abiotic factors, Food Reviews International. 19:1-2, 99-109, DOI: 10.1081/FRI-120018872
58. Jacobsen, S-E, Quispe, H., Mujica, A. (2001). Quinoa: an alternative crop for saline soils in the Andes. In: Scientist and Farmer-Partners in Research for the 21st Century. CIP Program Report 1999–2000, pp. 403–408.
59. Jacobsen, S-E, Stølen, O. (1993) Quinoa-morphology, phenology and prospects for its production as a new crop in Europe. European Journal of Agronomy.2 (1): 19-29. https://doi.org/10.1016/S1161-03019 (14)80148-2.
60. Jacobsen, S-E., Mujica, A., Jensen, C. (2003). The resistance of quinoa (Chenopodium quinoa Willd) to adverse abiotic factors. Food Rev. Int. 19 (1–2), 99–109. https://doi.org/10.1081/FRI-120018872
61. Jaikishun, S. Li. W., Yang, Z. & Song, S. (2019). Quinoa: perspective of global challenges. Agronomy, 9(4), 176.
62. Jensen, C., Jacobsen, S.-E., Andersen, M., Nun˜ez, N., Andersen, S., Rasmussen, L & Mogensen, V. (2000). Leaf gas exchange and water relations of field quinoa (Chenopodium quinoa Willd.) during soil drying. European Journal Agronomy 13 (1):11 – 25. DOI: 10.1016/S1161-0301(00)00055-1
63. Kammann, C., Linsel, S., GoBling, J. & Koyro, H. (2011). Influence of biochar on drought tolerance of Chenopodium quinoa Willd and on soil–plant relations. Plants and soil 345(1):195-210 DOI:10.1007/s11104-011-0771-5.
64. Lavini, A., Pulvento, C., d'Andria, R., Riccardi, M., Choukr-Allah, R., Belhabib, O., Yazar, A., Incekaya, C., Metin Sezen, S., Qadir, M., & Jacobsen, S. (2014). Quinoa's potential in the Mediterranean region. Journal of Agronomy and Crop Science, 200(5):344-360. https://doi.org/10.1111/jac.12069
65. Maamri, K., Zidane, O., Chaabena, A., Fiene, G. & Bazile, D. (2022). Adaptation of Some Quinoa Genotypes (Chenopodium quinoa Willd.), Grown in a Saharan Climate in Algeria. Life.12 (11): 1854. https://doi.org/10.3390/life12111854
66. Maliro, M. & Guwela, V. (2015). Quinoa breeding in Africa: History, Goals, and Progress. In: Improvement and Sustainable Production. John Wiley and sons Inc. (pp.109-124). DOI: 10.1002/9781118628041.ch9.
67. Maliro, M. & Njala, A. (2019). Agronomic performance and strategies of promoting Quinoa (Chenopodium quinoa Willd) in Malawi. (2019) Crop production. 46 (2): 82-99. DOI: 10.7764/rcia. v46i2.2143
68. Maliro, M., Abang, M., Mukankusi, C., Lung'aho, M., Fenta, B., Wanderi, S., Kapa, R., Okiro, O., Koma, E., Mwaba, C., Isse, M. & Bazile, D. (2021). Prospects for quinoa adaptation and utilization in Eastern and Southern Africa: Technological, institutional and policy considerations. Addis Ababa, FAO. https://doi.org/10.4060/cb2351en
69. Mansour, S. (2019). The Economics study of Quinoa Production to Reduce Food Poverty Gap in New Valley Governorate- Egypt. International Journal Agriculture Environmental research. 5(5) 31-39. DOI:10.53555/eijaer.v5i1.56.
70. Martínez, A., Veas, E., Jorquera, C., San Martín, R. & Jara, P. (2009). Re-introduction of quinoa into Arid Chile: cultivation of two lowland races under extremely low irrigation. J Agron Crop Sci 195(1):1–10. https:// doi. org/ 10. 1111/j.1439- 037X. 2008. 00332.x
71. Matanguihan, J., Maughan, P., Jellen, E. & Kolano, B. (2015) Quinoa Cytogenetics, Molecular genetics and Diversity. In: Quinoa; Improvement for sustainable production. https://doi.org/10.1002/9781118628041.ch7
72. McLaughlin, H. &Taylor, P. (2010). The Biochar Revolution: transforming agriculture and environment. NuLife publishing.
73. Mohapatra, D. & Bal, S. (2006). Cooking quality and instrumental textural attributes of cooked rice for different milling fractions. Journal of Food Engineering 73(3):253–9. https://doi.org/10.1016/j.jfoodeng.2005.01.028
74. Mujica, A. (1992): Granos y leguminosas andinas. In:J. Hernandez, J. Bermejo y J. Leon (eds). Cultivos marginados: otra perspectiva de 1492. Organización dela Naciones Unidas para la Agricultura y la Alimentación FAO.
75. Nanduri, K., Hirich, A., Salehi, M., Saadat, S. &

Jacobsen, S. (2019). Quinoa: A New Crop for Harsh Environments. Shabkha ecosystems. pp. 301- 333; DOI: 10.1007/978-3-030-04417-6_19

76. Nanduri, K., Hirich, A., Salehi, M., Saadat, S. & Jacobsen, S.E (2019). Quinoa: A New Crop for Harsh Environments. In: Sabkha Ecosystems. (pp 301-3330). https://doi.org/10.1007/978-3-030-04417-6_1
77. Oelke, E., Putnam, D. Teynor, T., Oplinger, E., (1992). Alternative field crops manual. University of Wisconsin Cooperative Extension Service, University of Minnesota Extension Service, Centre for Alternative Plant and Animal Products.
78. Otazu ́, V., Agular, P., Canahua, A. (1976). Resistencia en quinua (Chenopodium quinoa) al mildiu ́ (Peronospora effusa). Fitopatologı ́a 11:47 –49.
    a. Products. http://U.S.fao.org/faostat/en/#data/TP.
79. PROINPA foundation (2004), Study on the Social, environmental and economic impacts of quinoa promotion in Bolivia. Available online: https://www.cabi.org/wp-content/uploads/PROINPA-2004b-Social-impacts-Quinoa.pdf
80. Rekaby, S., Awad, M., Majrashi, A., Ali, E. & Eissa, M.(2021). Corn Cob-Derived Biochar Improves the growth of saline- irrigated quinoa in different orders of Egyptian soils. Horticulturae 7(8), 221.https://doi.org/10.3390/horticulturae7080221.
81. Risi, C., & Galwey, N.(1984). The Chenopodium Grains of the Andes: Inca Crops for Modern Agriculture. Advanced and Applied Biology 10 pp. 145-216.
82. Risi, J. & Galwey, N. (1991). Effects of sowing date and sowing rate on plant development and grain yield of quinoa (Chenopodium quinoa) in a temperate environment. The Journal of Agricultural Science, 117(3), 325-332.
83. Rojas, W. & Pinto, M. (2013). La diversidad genética de quinua de Bolivia. In M. Vargas, ed. Congreso Científico de la Quinua (Memorias). La Paz, Bolivia. p. 77-92.
84. Ruiz, K., Biondi, R., Oses, I., Acuña-Rodríguez, F., Antognoni, E., Martinez-Mosqueira, A.,Coulibaly, A., Canahua-Murillo, M., Pinto, A.,Zurita-Silva, D., Bazile, S.E. Jacobsen, and Molina-Montenegro, M. 2014. Quinoa biodiversity and sustainability for food security under climate change. A review. Agronomy for Sustainable Development. 34:349–359.
85. Scanlin, L. & Lewis, K. (2017). Quinoa as a Sustainable Protein Source. Sustainable Protein Sources. 223–238 https://doi.org/10.1016/B978-0-12802778-3.000147.
86. Ścisłowska, M., Włodarczyk, R., Kobyłecki1, R. & Bis, Z. (2015). Biochar to improve the quality and productivity of soils. Ecological Engineering .16(3):31-35. DOI: 10.12911/22998993/2802.
87. Shahbandeh, M. (2023). Global Quinoa production 2010-2021. Statista. https://www.statista.com/statistics/486442/global-quinoa-production/.
88. Simmonds, N. (1965). The grain chenopods of the tropical American highlands. Economic Botany**19**, 223–235 https://doi.org/10.1007/BF02914309
89. Singh, R., Bhatnagar, G., Shukla, A., Shivam, K., Verma, S., Supriya, A., Rakesh, K. & Meena, R. (2021). A Review: Nutritional, Medicinal and Economic Importance of Quinoa. Current research in agriculture and farming. DOI: http://dx.doi.org/10.18782/2582-7146.133
90. Thiam, E. Alloui & A. Benlhabib, O. (2021). Quinoa Productivity and Stability Evaluation through varietal environmental interaction. Plants 10.https: // doi.org/ 10.3390) plants1004714
91. Vega-Gálvez, A., Miranda, M., Vergara,J., Uribe, E., Puente, L. & Martínez, E. (2010). Nutrition facts and functional potential of quinoa (Chenopodium quinoa willd.), an ancient Andean grain: A review. Journal of Science Food and Agriculture. 90(15):254 1-7. doi:10.1002/jsfa.4158.
92. Wang, N., Wang, F., Shock C., Meng, C. & Qiao, L. (2020). Effects of management practices on quinoa growth, seed yield, and quality. Agronomy10 (3):445. DOI:10.3390/agronomy10030445.
93. Wieme, R., Reganold, J., Crowder, D., Murphya, K.& Carpenter-Boggs, L. (2020) Productivity and soil quality of organic forage, quinoa, and grain cropping systems in the dryland Pacific Northwest, USA. Agricultural ecosystems and environment. https://doi.org/10.1016/j.agee.2020.106838.
94. Wollf, E., Fung, I., Hoskins, B., Mitchell, B., Palmer, T., Santer, B., Shepherd, J. Shine, K., Solomon, S., Trenberth, K., Walsh, J. & Webbles, D. (2020) Climate Change, Evidence and Causes, Update 2020. National Academy of Sciences Royal Society. pp.1-36
95. Wu, G., Peterson, A., Morris, C. & Murphy,K. (2016). Quinoa seed quality response to sodium chloride and sodium sulfate salinity. Frontiers in Plant Sci. 7: 790. https://doi.org/10.3389/fpls.2016.0079
96. Ya ́ bar, E., Gianoli, E., & Echegaray, E., (2002). Insect Pest and natural enemies in two varieties of quinoa (Chenopodium Quinoa) at Cusco, Peru. Applied Entomology. 126 (6): 275–28 DOI:10.1046/j.1439-0418.2002. 00664.x