Climate Change: Challenge of Introducing Quinoa in Southeast European Agriculture

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Abstract

The aim of this chapter is to describe the potential effects of climate changes in Southeast European (SEE) countries, and the implications on agricultural production. Adaptation measures to mitigate these effects could be to introduce new crops tolerant to various stress factors, such as drought, saline soils, and varying temperatures. Quinoa is a plant that has great potential for growing in such unfavorable conditions. In the presented review, we explain the origin, importance, and application of quinoa in agriculture with special emphasis on its nutritional and health significance as well as the mechanisms of resistance to stress factors. The opportunities for quinoa breeding in SEE are presented on the basis of data from Greece, Romania, Serbia, North Macedonia, and Turkey, varying depending on local agroclimatic conditions. The nutritional composition of the quinoa seeds is of very high value also when grown under rain-fed conditions in Serbia. There were good results from adding quinoa to wheat bread. Conclusions are that although the quinoa market in SEE is not as large as in other European countries, it is growing very intensively, and the food industry is developing new quinoa products. Thus, the prospects for future quinoa production in SEE countries are promising.

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16.1 Introduction

Climate change is one of the most important threats facing the world today. The predictions of the Working Group of the Intergovernmental Panel on Climate Change are that global mean temperatures will continue to rise together with greenhouse gas emissions until the end of the twenty-first century (IPCC 2013). Global temperatures will be 1.5 °C higher in the period 2081–2100 compared to the period between 1850 and 1900. Atmospheric concentrations of carbon dioxide increased from a pre-industrial value of 278 ppm and reached 403 ppm in 2017 (WMO 2019). Also the frequency, duration, and magnitude of hot extremes along with heat stress are expected to increase, and changes in average precipitation will exhibit spatial variation. Annual runoff is projected to decline in parts of southern Europe, the Middle East, and southern Africa, with an increase in northern latitudes expected by the end of the twenty-first century.

Agriculture is especially dependent on climate factors, and it is expected that climate change will limit agricultural production and food security. Increases in temperature and extreme weather events (heat waves, storms, flooding effects) as well as reduced water reserves are expected to be more frequent in the future. According to Wiebe et al. (2019), projections at the global scale in 2050 indicated that yields of major crops (cereals, oilseeds, and sugar crops) will decline by 5–7%, while food prices will increase by 10–15%, relative to proposed levels in the absence of climate change.

Therefore, predictions are that climate variability will have significant impacts on crop production and food security at both global and local levels. The United Nations predictions are that the world population will reach 9.8 billion in 2050 and 11.2 billion in 2100, which means that food sustainability in a stressful environment will become one of the most important future challenges. Increased demand for food due to population growth and changes in global food consumption patterns will increase pressure toward more sustainable agricultural production and adaptation, and mitigation measures (Campbell et al. 2016; Wheeler and von Braun 2013).

In response to climate change, the adaptive capacity of the agricultural sector must be increased. According to EEA report (2019), this should include a number of adaptation measures at national, regional, and farm level. Measures at the national and regional levels primarily involve farmers and measures to raise their awareness of these changes and provide appropriate advice that they can apply to their farms. Integrating adaptation into farm advices includes risk management insurance against climate, improving irrigation efficiency and infrastructure, and flood management prevention. Adaptation measures at the farm level depend on the specific climate impact, economic situation, farm size, cultural background, and farmer education.

These measures are numerous, including the use of appropriate agronomic methodology (altering sowing and harvesting time, use of new crops, crop rotation, improved irrigation and fertilization techniques, variation in cropping schemes, etc.) (Jacobsen et al. 2013, 2015; Raza et al. 2019).

Measures to cope with extreme climate condition effects on crops (especially drought and high temperature) also include different genetic and molecular approaches as genome targeting selection (genetically engineered plants for stress tolerance, stress-resistant genotypes). One of the possible approaches is also to introduce in agricultural production ancient crops resistant to various stress factors, such as quinoa.

Quinoa (*Chenopodium quinoa* Willd.) belongs to the Amaranthaceae family, originating from the Andean region of South America. It has recently expanded all over the world (Bazile et al. 2016). The crop currently is in focus due to its high potential for becoming a new food (Ruiz et al. 2014) and its high tolerance to various abiotic stress factors (Nanduri et al. 2019), including frost (Jacobsen et al. 2005, 2007), drought (Hirich et al. 2014a, b; Jacobsen et al. 2009; Razzaghi et al. 2012a, b, 2015), salinity (Adolf et al. 2012, 2013; Becker et al. 2017; Bonales-Alatorre et al. 2013; García et al. 2003, 2007; Ismail et al. 2016; Iqbal et al. 2019; Jacobsen 2003, 2017; Lavini et al. 2016; Panuccio et al. 2014; Riccardi et al. 2014; Shabala et al. 2013; Sun et al. 2017; Yang et al. 2016b, 2017), heat (Yang et al. 2016a), as well as its exceptional nutritional value of seeds (Repo-Carrasco et al. 2003) and vegetative parts.

According to FAO (2013a), the advantage of quinoa is that it can be considered a multifunctional agricultural crop that can be used in human and animal nutrition as well as in medical or industrial applications. The seeds and leaves can be used for human food as different products (bread, pastries, sauces, soups, noodles, desserts, etc.). For animal feed, the whole plant can be used as green forage. The potential medical use of quinoa is for wound healing, reduction of swelling, soothing pain, etc., as well as for other industrial uses (saponins for shampoos, detergents, toothpastes, pesticides, etc.). The nutritional and health-promoting values of quinoa seeds and leaves are the result of a high content of minerals, vitamins, proteins, and other important multiple bioactive compounds (Hernández-Ledesma 2019). The nutritional value of quinoa and its health-beneficial aspect (especially as a gluten-free culture) have attracted the attention of many consumers of healthy diets, so the world and European markets for quinoa as "superfood" are growing significantly. Thus, quinoa is recognized as one of the crops with an important role in ensuring future food security, also demonstrated by the FAO designated year 2013 as the "Year of Quinoa" (Bazile et al. 2015).

This chapter reviews the effects of climate change on crop production in Southeast Europe (SEE) with the focus on the possibility to cultivate quinoa in the region as a stress-resistant crop. The special emphasis is on the possibility for introducing quinoa production in Serbia as a SEE country with agro-meteorological characteristics of agriculture similar to other SEE countries.

16.2 Climate Change Projection in Southeast Europe

The projections are that climate changes in Europe such as global warming as a result of elevated anthropogenic greenhouse gas emissions, and uneven distribution of rainfall, will affect the decisions to be taken in agricultural production. Future climate scenarios indicated the probability for increasing mean temperatures (1.5–2 °C) across Europe with characteristic pattern leading to a substantial increase of temperatures in North Europe during the winter, and in Southeast Europe and Mediterranean regions during the summer (IPCC 2018). Along with temperatures, an increase in water availability is also predicted in central and northern Europe, while water shortages in southern Europe, particularly in Italy, Greece, Portugal, Spain, and Turkey (Bisselink et al. 2018).

As a result of current climate change, rising temperatures, and lack of precipitation, droughts are predicted to occur in Europe by the end of the twenty-first century. However, there are two different possible scenarios about this climate phenomenon. According to the moderate climate scenario (RCP 4.5), frequency and intensity of drought will rise in the Mediterranean, western Europe, and Northern Scandinavia, whereas severe climate scenario (RCP 8.5) predicted the appearance of intensive droughts in all Europe. Taking into account both scenarios, drought frequency will increase during spring and summer (especially in southern Europe) and decrease in winter over northern and western Europe (Spinoni et al. 2018).

Projected climate changes for 2071–2100, compared to 1971–2000, based on the average of a multi-model ensemble with RCP 8.5 scenario indicated that annual average temperatures will increase over eastern and northern Europe as well as southern Europe (EEA 2015). However, annual precipitation is generally projected to increase in northern Europe and to decrease in southern Europe and highlighted the differences between wet and dry regions (Fig. 16.1). The increased risk of climate change will affect not only Mediterranean countries but also Southeast European countries. Southeast Europe or Southeastern Europe (SEE) is a geographical region of Europe, consisting primarily of the Balkan Peninsula. There are overlapping and conflicting definitions as to where exactly Southeastern Europe begins or ends or how it relates to other regions of the European continent. States and territories that are usually included in the SEE region are Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Greece, Montenegro, North Macedonia, Romania, Serbia, as well as East Thrace as European part of Turkey (Fig. 16.1).

Climatic conditions in the SEE countries range from temperate continental climate (Serbia, lowlands and mountains areas of Bosnia and Herzegovina, Croatia, the northern parts of Montenegro and North Macedonia, Greece, Romania, Bulgaria, and European part of Turkey) to Mediterranean and sub-Mediterranean climate (Albania, the southern part of Montenegro and North Macedonia, and coastal areas of Croatia, Bosnia, and Herzegovina, Montenegro, Greece, and Bulgaria).

Cheval et al. (2017) evaluated past and projected variability of the air temperature, precipitation, evapotranspiration, and aridity in SEE throughout 1961–2050 periods. The data were aggregated from three regional models (RegCM3, ALADIN-Climate, and Promes) at 25-km spatial resolution. Their study confirmed that the

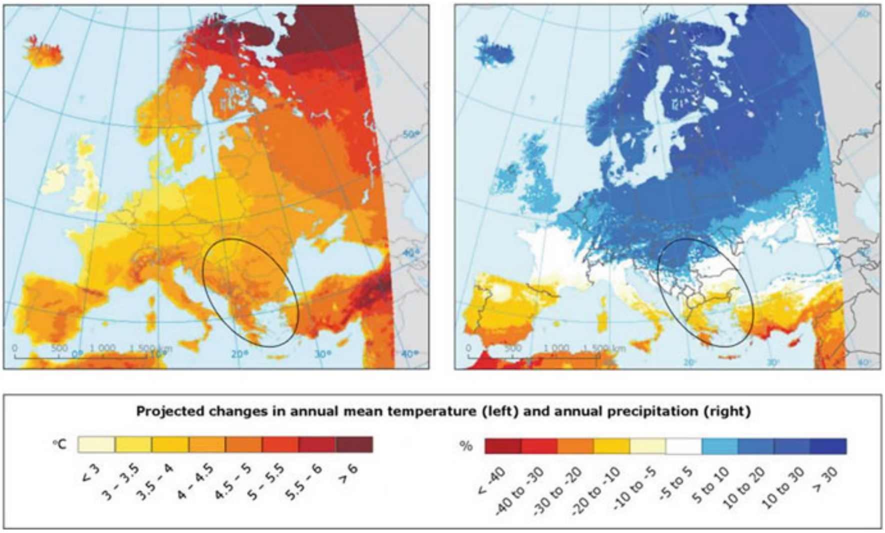

Fig. 16.1 Projected temperature and precipitation changes in Europe for the period 2071–2100 based on an ensemble of regional climate model simulations (modified from EEA 2015). The marked sections on the maps indicate the region of Southeast Europe

Southeast Europe is warming, with the important qualitative shifts toward more aridity will occur over Pannonian Plan, in the proximity of the Black Sea and in Eastern part of the Balkan Peninsula. In general, water is one of the most of important climate change factors in the SEE region because the availability of water resources (for municipal, industrial, and irrigation purposes), forestry and agriculture, biodiversity, and human health is declining.

Greece is particularly vulnerable to climate change. Its climate varies from Mediterranean, with mild and humid winters in the southern lowlands and island regions, to cold winters with heavy snowfall in mountainous regions in the central and northern regions. Greece also has a very long coastline of 16,300 km, of which around 1000 km are areas highly vulnerable to climate change compared to other regions. The World Bank Climate Change Knowledge Portal (n.d.) projection for Greece by 2050 is that mean annual temperature will rise by 2.3 °C. Similar forecasts are for Montenegro (mean annual temperature will rise by 2.4 °C, annual precipitation will fall by −35.2 mm, and total annual hot days of temperature above 35 °C will rise by 2.2 days) and for North Macedonia.

The USAID (2017) has also proposed a Climate Change Risk Profile for others of the SEE countries by 2050 year. Climate scenarios for Albania include intense temperature increase (2.4 °C–3.1 °C) from June to August; decreased annual precipitation (less than 10%), with the greatest decrease from June to September; an increase in precipitation that falls as rain instead of snow, potentially reducing snowfall; an increase in intensive episodes of rain; and floods along coastlines with a rise from 48 to 60 cm sea level by the year 2100. For Serbia projected changes are an increase in average annual temperature of 1.5–2.2 °C; decrease in average annual precipitation of 1.1–3.5%, with the largest reductions in July and August; an increase in the number of dry days by 11–18%, and 21–31% increase in total annual precipitation on extreme rainfall days. Bosnia and Herzegovina and Croatia are also highly vulnerable to the impacts of climate change, especially in the coast and coastal zones.

The further prediction for global warming in Serbia, as a Southeast European country, is more serious with an increase in mean temperature over 2.5 °C according to the moderate climate scenario (RCP 4.5) and over 5 °C under the severe scenario (RCP 8.5). Extended periods of drought combined with heat waves and low precipitation, especially in summer, indicate that there is a trend of warming in Serbia, which is particularly pronounced in the central and southern parts of the country (Vuković et al. 2018).

16.3 Climate Change Impacts on Agriculture

Agriculture is a very vulnerable sector to climate change. It can be directly influenced by changes in crop growth and phenology (due to significant increases in CO_2 levels and temperature), but also by the more frequent appearance of extreme events (heat waves, frost, droughts, floods, hail storms, reduced water resources) and increasing the risk of plant diseases and pests. Also, the indirect impact on agricultural production will have a significant social and economic effect on global level, as increasing occurrence of extreme climate events will negatively affect trade sector, farmer income and agribusiness sector, food chain supply, or food security (EEA 2017; FAO 2016).

To mitigate the effects of climate change on agriculture, the FAO introduce the climate-smart agriculture (CSA) concept in the most vulnerable regions and countries. The CSA system is associated with actions to address the specific needs of local farms by incorporating technologies that are adapted to increase agricultural productivity and income and to reduce greenhouse gas emissions, where possible (FAO 2013b; Lipper et al. 2014).

Europe’s agriculture is also vulnerable to climate change. Considering a wide range of variable climatic conditions across Europe, as well as the types and uses of land and vegetation, it is expected that these differences could have significant and different impacts on crop production and diversification (Blanco et al. 2017). The climate changes are predicted to be less negative on crop productivity in northern Europe than in southern part where is expected to decline. Changes in crop phenology will result from faster crop development (shorter crop growing cycles) and the negative effects of high temperatures and water deficits on yield, especially during the reproduction phase (flowering and grain filling) when crops are particularly sensitive to adverse factors (Olesen et al. 2011).

As a result of climate change in Europe, a continuous trend of change in the agroclimatic zone of eastern Europe (especially continental) in relation to northern

Europe has been observed (Ceglar et al. 2019). This will lead to a decrease in crop-specific cultivation (mainly due to high temperatures and frequent droughts) in some regions of Southeastern Europe and the Mediterranean, while the northern European regions become more favorable areas for crops originating from the warm season (King et al. 2018). On the basis of such forecast, an increase in the yield of rain-fed crops in central and northern Europe is expected, while for southern Europe, an opposite trend and a decrease in crop yield are expected for the period 2021–2050 (Ciscar et al. 2018).

Climate change risk presents a potential threat for European agriculture, since some projections indicated up to 16% loss in agriculture income by 2050, with large regional variations (IPCC 2019). A study of the potential impact of climate change on yields has indicated that the most negative effect will be on the yield of dominant crops (maize, wheat, barley, soybeans) as it will be reduced by 6.3–21.2% in western and southern Europe (Ray et al. 2019). Also, currently, extreme weather events (heat waves, storms, flooding) and especially high temperature and drought have caused yield declines in southern Europe. At the end of the twenty-first century, Greece should expect a long-term negative impact on cereals, especially wheat and barley (Mavromatis 2015). Climate problems also occur in northern Europe, for example, in 2018 there was a drought, because there was no precipitation during the summer for 3 months.

The impact of climate change on agriculture is also a challenge for the economy of Southeast Europe, especially in the Western Balkan region, given the important role of agriculture and its contribution to gross domestic product (GDP). The contribution of agriculture to GDP in SEE countries varies from 3.00% in Croatia to 18.44% in Albania in 2018 (The Global Economy n.d.). Global warming together with extreme events (very frequent and intense droughts and floods) predicted for all Southeast European countries could significantly reduce crop yields, especially maize (OECD 2018). Under these conditions, fungal diseases and pests are also expected to increase, which will further reduce crop yield and quality.

The negative impact of climate change on crop production and agriculture in Serbia is similar to the change in other SEE countries. Droughts in Serbia are most prevalent in the eastern and northern part of country, and the Vojvodina region, as the most important agricultural area. It is expected that drought up to the end of the twenty-first century will have significant negative effects on the yield of both winter and summer crops (FAO 2018). In Serbia, most of the agricultural production takes place under rain-fed conditions, so the expected climate change (drought and high temperatures) will greatly reduce the yield of different crops, especially in the summer months. Predictions of regional climate models for the period up to the end of the twenty-first century and for maize as a strategically important crop for Serbian agriculture and mainly grown in rain-fed conditions are that its yield will decrease by 52% due to high temperatures and reduced rainfall during the summer months (Mihailović et al. 2015). Extreme events (high temperature, heavy rainfall, etc.) can also reduce the production of fruits and cereals that are the most important agricultural products in terms of production areas and economic output (USAID

2017). It is expected that the impact of climate change on agriculture in other SEE countries will be similar to the effect on Serbia.

Projected changes in the impact of climate change on crops under the SRES scenarios (A2 and B1) indicate that in 2030, wheat yields will increase by 21–22% in Greece and by 7–13% in other parts of southern Europe, while maize yields decline in the Balkans and Southeast Europe (Greece, 4%, others, 2–7%), and this trend will further continue until 2050 (Supit et al. 2012). Although climate scenarios generally predict the adverse impact of climate change on agriculture, there are many sources of uncertainty that should be considered when interpreting the results for specific countries and regions. These predictions should take into account changes in CO_2 concentration, precipitation, and temperature, as well as soil quality characteristics and management, and type of crop traditionally grown in certain regions. Some climate models such as those of Donatelli et al. (2012) could have significant practical application in 27 EU Member States. They would enable the identification of areas where adaptation, like those simulated, may be run autonomously by farmers growing wheat, rapeseed, and sunflower. Given that the examined crops and conditions expected in Greece are similar to those of neighboring countries, such as Italy, Spain, southern France, and Cyprus, as well as some regions of the Balkan Peninsula and Turkey (Georgopoulou et al. 2017), these findings may provide useful insights into the implementation of similar adaptation measures in these countries.

Adaptation measures to mitigate the reduction in yields caused by climate change include the cultivation or testing of the use of species that are resistant to various abiotic stress factors but are underutilized globally. One of these species is quinoa which is native and traditional from the Andean region of South America. The increasing interest in quinoa cultivation in the world is associated with its exceptional nutritional and health-beneficial properties and its ability to withstand abiotic stresses.

16.4 Quinoa as Promising Alternative Crop for Climate Changes

Quinoa (*Chenopodium quinoa* Willd.) is an Andean grain crop belonging to the Amaranthaceae family and originated from South America (the Andean region—Peru, Bolivia, Chile, Argentina), where it has been traditionally cultivated for more than 7000 years as a native food (Jacobsen et al. 2003). The Andean region with diverse agroecological conditions related to geographic positions (from coastal and inland saline soils, arid and semiarid land to highlands with harsh conditions) has created the opportunity for developing a large biodiversity of quinoa. Quinoa can be divided into main five ecotypes associated with a specific area in this region (Bazile and Baudron 2015; Fuentes et al. 2012). Due to its broad genetic variability and ability to adapt to different biotic and abiotic stress factors, quinoa has a huge potential to spread widely all over the world. There are 16,422 accessions of quinoa, and its wild relatives in gene banks are distributed in 30 countries worldwide (Rojas et al. 2015). The FAO together with the Universidad Nacional del Altiplano de Puno and CIP organized a worldwide test of quinoa which provided valuable results, and induced an interest for the crop in many countries (Izquierdo et al. 2003; Jacobsen 2003), later followed up by other tests, mainly in Africa and Central Asia (Bazile et al. 2016).

16.4.1 Nutritional Importance and Health Characteristics

Quinoa was known by the Incas as the "mother of grains," and according to the legend, the Incan armies during their war periods consumed an energy-rich mixture of quinoa and fat known as "war balls." Quinoa is also called "grano de oro" (**golden grain**) by the local people, and the name refers to the shiny golden appearance of the seeds and also to the high nutritional value of this crop.

Pericarp of quinoa seed contains saponins, plant glycosides that create a bitter taste for seeds. They are water-soluble compounds that can be easily removed by washing, soaking, quinoa boiling, or mechanical abrasion (Ruiz et al. 2017b). The amount of saponins present depends on the variety of quinoa. Jarvis et al.'s (2017) results indicated that the content of saponin in seeds is correlated with seed coat thickness, with the bitter lines having significantly thicker seed coats than sweet lines. The same research group has identified one of the genes that they believe controls saponin production in quinoa, which would make it easier to develop saponin-free varieties.

The nutritional value of quinoa is high due to its high protein content, but especially their high quality. In addition quinoa contains several important minerals, vitamins, and other important multiple bioactive compounds (Gordillo-Bastidas et al. 2016; Maradini-Filho 2017; Repo-Carrasco et al. 2003; Stikic et al. 2012).

The exceptional nutritional quality is based on a high content of proteins (13.1%–16.7%) with the essential amino acids (lysine, methionine, threonine, and tryptophan) that are scarce in cereals and legumes (Vilcacundo and Hernández-Ledesma 2017). This makes quinoa a superior crop compared to cereals, such as wheat and rice. The protein content is similar to eggs (13–14%), but much higher than in cow and human milk (3.50 and 1.80, respectively), indicating that quinoa could be an ideal food for humans and animals (FAO 2011). Carbohydrates are a major component of quinoa seeds (59.9–74.7%), both primary starch and also individual sugars (maltose, galactose, ribose). Together with the high content of dietary fiber (7.0–11.7%), quinoa is an ideal source of energy (Vilcacundo and Hernández-Ledesma 2017). Seeds are also rich source of lipid components (5.5–7.4%) with high quality of essential fatty acids (linoleic and alpha-linolenic acids), and other lipophilic phytochemicals (including carotenoids). Quinoa seeds also have a higher mineral content than other cereals (Ca, Fe, K, Mg, P, Zn, Mn), and some of them, such as K, Ca, and Mg, are in bioavailable forms, and their content is adequate for a balanced diet (Vega-Galvez et al. 2010).

Important components are vitamins, and levels of riboflavin (B2), pyridoxine (B6), vitamin E (tocopherol), and folic acid are higher than in wheat and rice. Also, high levels of vitamin C found in quinoa seeds (4.0–16.4%) along with vitamin E have a significant role as a powerful antioxidant against oxidative stress (Vilcacundo and Hernández-Ledesma 2017).

Quinoa is also used for people with celiac disease (allergy to gluten), as a suitable replacement for the cereals wheat, rye, and barley, which all contain gluten (Peñas et al. 2014). Because of all these excellent characteristics, quinoa is considered a "golden grain," and the NASA has integrated it into the diet of astronauts (Arneja et al. 2015).

In addition to its exceptional nutritive characteristics, quinoa has a very good health characteristic and is defined as "natural functional food." Its antioxidant and anti-inflammatory compounds provide a beneficial effect on human health in preventing the risk of various serious diseases such as a diabetes 2, cardiovascular disease, and cancer (Navruz-Varli and Sanlier 2016; Tang and Tsao 2017).

The beneficial effects on health are primarily based on the high content of antioxidants (including polyphenols, flavonoids), and other important multiple bioactive compound (Lutz and Bascuñán-Godoy 2017; Repo-Carrasco-Valencia et al. 2010). Quinoa seeds contain a variety of hydrophilic (e.g., polyphenols and betalains) and lipophilic components (polyunsaturated fatty acids, carotenoids, and tocopherols) with high antioxidant activities that contribute to reducing the risks of oxidative stress related to different diseases (Abderrahim et al. 2015; Tang et al. 2015). Important phytochemicals in quinoa seeds are phytosterols and phytoecdysteroids. Various studies have shown that that phytosterols as a lipophilic compound could have a hypocholesterolemic effect in humans while some bioactive phytoecdysteroids from quinoa seeds significantly lower blood glucose and have antidiabetic properties (Graf et al. 2014). Recent results have also shown that saponins, as a component of quinoa seed pericarp, also have a wide range of biological activities relevant to human health, including antifungal, antiviral, anticancer, hypocholesterolemic, hypoglycemic, antithrombotic, diuretic, and anti-inflammatory activities (Graf et al. 2015).

In some species of *Chenopodium*, bioactive compounds with antioxidant and cytotoxic properties were extracted from various plant parts (Nowak et al. 2016). Although there is limited literature on the cytotoxic activity of quinoa, recent results have shown that extracts from quinoa leaves or seeds can have a cytotoxic effect on various types of cancer in humans, including liver and breast (Hu et al. 2017) and cervical carcinoma (Paśko et al. 2019). High content of phenolics as well as high antioxidant activity contributed to the effect of quinoa leaf extract against prostate cancer (Gawlik-Dziki et al. 2013). Also, various bioactive quinoa polysaccharides exhibit in vitro significant antioxidant, immunomodulatory, and anticancer effect (Yao et al. 2014). Currently, in vitro gastrointestinal digestion study indicates that bioactive peptides released from quinoa seed proteins have chemopreventive potential that act as an anticancer compound (Vilcacundo et al. 2018). Our latest results show that seed extracts of Puno and Titicaca cultivars grown in Serbia in 2018 contain significant amounts of phenolic and flavonoid components and exhibit strong antioxidant activity and potential anticancer activity against the human colorectal cancer cell line HCT-116 (Stikić et al. 2020). All the previously mentioned positive effects of quinoa nutrient components on human health support the fact that quinoa exhibits great potential that can be used as a food ingredient or as a drug component to modify the human immune system against serious diseases. Saponins in pericarp of quinoa seeds are also useful for protecting crops against microbial infection and insect and bird herbivory (Graf et al. 2015).

16.4.2 Quinoa as a Stress-Resilient Crop

Quinoa, which originates from the Andean region with harsh climatic conditions, is exposed to temperatures from −4 to 38 °C, humidity from 40 to 88%, poor soil quality, and rain-fed conditions (FAO 2011; Jacobsen 2011). Due to such different environmental conditions, quinoa is a well-adapted culture to most of these abiotic stress factors, including low temperatures, frost, drought, soil salinity, wind, and hail (Hinojosa et al. 2018; Jacobsen 2011).

The most common abiotic stress factors are drought and salinity, which are widely presented and have a significant impact on crop growth and productivity. Knowledge of tolerance mechanisms is important for drought and salt mitigation through different approaches: introducing tolerant genotypes as well as land and water management strategies to increase water productivity in drought- and salt-prone regions.

Quinoa is well adapted to drought conditions, thanks to a variety of mechanisms including drought escape, avoidance, and tolerance (Jacobsen et al. 2003; Zurita-Silva et al. 2015). As one of the earliest approaches in crop stress physiology, drought escape is based on faster plant development and early maturity (before stress becomes serious).

Quinoa drought avoidance mechanisms include different morpho-anatomical and physiological changes in order to reduce water loss by transpiration and increase water uptake *via* the root system. Morpho-anatomical changes include both changes at leaf level (small leaf area, cells with thick wall, leaf dropping, epidermal cell bladder) and root level (deep and dense root system) (Jacobsen et al. 2003; Jensen et al. 2000). Physiological responses are based on the control of stomatal conductance in order to maintain leaf water potential and photosynthesis, where an elevated ABA concentration in leaves and xylem could make an important contribution to the stomatal response, which is largely genotype dependent (Jacobsen et al. 2009; Razzaghi et al. 2011; Sun et al. 2014).

Drought tolerance in quinoa is achieved by different mechanisms, from tissue elasticity and osmotic adaptation based on the accumulation of osmolytes (soluble sugars, proline) and inorganic ions (Jacobsen et al. 2003; Jensen et al. 2000), higher stomatal control and maintenance of photosynthetic activity (González et al. 2011), activation of antioxidant enzymes (Fgire et al. 2013), and gene expression of stress proteins (osmoprotectants, HSP) as well as associated with ABA biosynthesis (Liu et al. 2018; Morales et al. 2017).

A drought tolerance study of varieties of quinoa of different origin highlighted the importance of genotypic differences, as Danish (Titicaca) variety was more sensitive to progressive droughts than varieties originating in Bolivia (as Achachino) (Sun et al. 2014).

During quinoa development, one of the most vulnerable stages of drought, as well as critical for determining yield, is the flowering and milk grain phase when water supply is important. The later stages are less sensitive, creating the opportunity for water management to apply a reduced amount of irrigation water by applying different irrigation strategies as deficient irrigation techniques. Several field studies at different locations in the Bolivian region of the Altiplano have demonstrated that deficit irrigation techniques can result in good quinoa yields and high crop productivity (Geerts et al. 2008, 2009). Experiments with the Danish cultivar Titicaca have shown a tolerance to soil drying during the seed-filling phase and that the use of deficit irrigation can maintain quinoa yield and improve water productivity and save water for irrigation (Razzaghi et al. 2012b). The application of different deficit irrigation techniques in the experiment with the same cultivar showed that alternating root zone drying in combination with high temperatures induces a better adaptive response related to growth and biomass and an increase in WUE (water-use efficiency) compared to deficit irrigation (Yang et al. 2016a). Successful application of deficit irrigation techniques to maintain quinoa yield and at the same time save water for irrigation is important for drought-prone and semiarid areas where drying and rewetting events occur occasionally, and may be more frequent depending on predicted climate change.

The experiment of Ahmadi et al. (2019) done with the newly released quinoa cultivar (cv. K5) showed that a vigorous root system extending up to 1.2 m of soil helps the quinoa to increase water-use efficiency from irrigated soil. By using a suitable cultivar and adjusting the appropriate planting density and managing the water saving of irrigation, quinoa as a “super crop” has the potential to grow successfully and produce yield even in hot and semiarid regions.

Recent results also suggested that different soil applications could improve the response of quinoa to drought. A study in which N fertilization was applied in drought conditions showed a positive impact on quinoa yield and physiology and highlighted the role of N remobilization in sustaining seed yield under drought stress (Alandia et al. 2016). Also, various organic amendments added to the soil (compost and acidified biochar) together with applied deficit irrigation techniques can improve quinoa growth and yield quality, which is related to the biochemical attributes of quinoa seeds in drought conditions (Hirich et al. 2014a, b).

Salt stress is a very common abiotic factor, and quinoa is well adapted to varying levels of soil salinity, as a facultative halophyte. There are several mechanisms by which quinoa adapt to the saline environment, and most of them are similar to the reaction to drought. Quinoa response to salinity includes morpho-anatomical properties (stomatal density and epidermal salt bladders) as well as physiological and metabolic reactions such as stomatal regulation and photosynthesis, osmoregulation, K^+ retention and Na^+ loading, transport and storage, and gene expression of membrane transporters (Ruiz et al. 2015). The main response against osmotic and ionic stress under salinity is osmotic adaptation based on the primary accumulation of salt ions (Na^+, K^+, Cl^-) in tissues, as well as organic osmolytes that regulate the leaf water status and maintain the cell turgor (Hariadi et al. 2011; Jacobsen and Mujica 2003; Shabala et al. 2012). Similar to the drought response, salt stress also triggered an antioxidant response in quinoa by increased activities of superoxide dismutase, catalase, ascorbate peroxidase (Amjad et al. 2015), and molecular, ABA-related response (Ruiz et al. 2017c).

Quinoa shows a high tolerance to soil salinity, but with significant varietal differences. Some varieties can grow in salt concentrations similar to those in seawater or even higher (Adolf et al. 2013; Jacobsen et al. 2003). Such a response made it possible to use quinoa for cultivation not only in the saline area but also in regions where it is possible to use saline water for irrigation (Mediterranean and similar regions).

Drought and salt stress interactions are often presented in some regions, and the quinoa response to these adverse factors depends on the type and intensity of stress. The experiments with cv. Titicaca indicated that the interaction of severe salinity and water deficit did not adversely affect the total dry matter production but increased the water productivity of dry matter (Razzaghi et al. 2012a). A similar effect with the same cultivar was observed in a field study in Southern Italy, where saltwater irrigation together with drought stress did not significantly reduce quinoa yield (Pulvento et al. 2012). Investigation of the ecophysiological characteristics of quinoa cultivation in field conditions in Southern Italy has shown good resistance to drought and salt stress through stomatal reactions and osmotic adaptations, which play a central role in maintaining plant growth and preserving crop yield (Cocozza et al. 2012). On the contrary, the results of a field trial where saline water was use for quinoa irrigation in Adana, Turkey, showed that the interaction of salinity and drought stress (induced by different deficit irrigation techniques) significantly reduced crop grain and biomass yields. However, salinity stress alone did not significantly affect grain and biomass yield (Yazar et al. 2015a).

Along with high tolerance to adverse abiotic factors, quinoa can also mitigate ecosystem changes as a consequence of global warming and increased anthropogenic activities, such as desalination and phytoremediation (Jaikishun et al. 2019). Various studies have shown that quinoa is also suitable for cleaning polluted soil by phytoextraction of heavy metals such as Ni, Cr, Cd, Fe, Cu, Zn, and Cr (Bhargava et al. 2008; Ruiz et al. 2017a). Quinoa also has the ability to hyperaccumulate Pb in various plant organs, and despite this its concentration in seed remains within safe limits recommended for human use (Haseeb et al. 2018), which highlighted the role of quinoa as a superior crop.

16.5 Challenges and Opportunities for Growing Quinoa in SEE Region

With the increasing impact of climate change on traditional agricultural crops, it is very important to introduce into agricultural production plants that are grown as specific representatives of biodiversity in particular localities, including SEE. Introducing quinoa as an ancient plant resistant to different climatic effects is the best example of this approach. The great genetic potential of quinoa, its resistance to various climatic factors, and significant nutrient and health-beneficial effects have enabled quinoa production to expand from the South American region to other parts of the world.

The largest quantities of quinoa seeds used for food are still imported from South America (especially Bolivia and Peru), but also many other countries, including the USA, Canada, and some European countries (France, Spain, Denmark, Italy), aspire to enter the world market by commercially cultivating and exporting quinoa, and some small companies are breeding and selecting new cultivars. Knowledge of the quinoa genome is of particular importance for the breeding of new quinoa cultivars and successful selection for growing quinoa in particular regions. Recently the genetic structure of quinoa was mapped, allowing genetic modification, which may prove crucial for increasing the productivity of quinoa crops and explaining its resistance to stress (Jarvis et al. 2017).

Since quinoa is a new food crop for cultivation in many countries including SEE, it is a challenge to encourage and educate farmers and agricultural companies to introduce quinoa as an alternative stress-resistant crop in their field programs. In order to successfully cultivate quinoa in a specific locality and region, in addition to selecting a specific variety, a number of agronomic studies have to be carried out that would allow for optimal yield and income. These include analyses of soil fertility; sowing time and plant density; fertilization and irrigation needs; morphological traits and phenological stages; control of pests, diseases, and weeds; and identification of seed maturity and harvest time. The lack of modern and appropriate machinery for sowing or harvesting very small quinoa seeds may be a limiting factor. Therefore, the cost of labor in some countries can increase the cost of quinoa production. All this requires the advancement of cultural practices and technologies for the cultivation of quinoa in a specific locality. The choice of quinoa varieties must also take into account the effects of climatic conditions in a given region and stress factors. The appearance of drought during flowering or grain filling phase could significantly reduce yields in many crops, but due to a higher drought tolerance of quinoa compared to other crops, these negative effects would be less expressed (Zurita-Silva et al. 2015).

According to Jacobsen (2017) in Europe, there are nine registered cultivars, that is, five from the Netherland (Carmen, Atlas, Pasto, Riobamba, and Red Carina), three from Denmark (Titicaca, Puno, and Vikinga), and one from France (Jessie). Präger et al.'s (2018) results have shown that of these European varieties, four are suitable for cultivation in southwestern Germany (Puno, Titicaca, Jessie, Zeno) with regard to grain yield, thousand kernel weight, saponin and protein contents, crude fat content, amino acid profile, and fatty acid profile.

Similarly, to the other part of Europe, experiments aimed at testing the opportunities for quinoa cultivation in SEE countries have shown that there is great potential to expand organized quinoa cultivation. Cultivation of quinoa was tested in different regions of Greece (Iliadis et al. 2001; Karyotis et al. 2003; Noulas et al. 2017), Serbia (Glamoclija et al. 2010; Stikic et al. 2012), North Macedonia (Bosev et al. 2007), Romania (Szilagyi and Jornsgard 2014), and in some regions in

Turkey (Geren 2015; Tan and Temel 2018; Yazar and Ince Kaya 2014; Yazar et al. 2015a, b).

Danish quinoa cultivars are well adapted to northern Europe with average yields ranging from 1 to 3 t/ha (Jacobsen 2017) but have also shown the best adaptation and suitability to local climatic conditions in most Southeast European countries. In studies with numerous quinoa varieties of different origins (including European and Latin American) growing in lowlands in central Greece with characteristic warm and dry climates, the average grain yield was about 1–1.5 t/ha, with some varieties having high protein levels (15–18.5%) and mineral content. Among them, the Danish varieties had a seed yield of 1.3 t/ha (Noulas et al. 2017). The coastal parts of Greece have characteristics of the Mediterranean climate. Recent results have confirmed the great potential for quinoa production in the Mediterranean region, which is characterized by highly variable climates with hot, dry summers, but also cold and rainy winters (Bilalis et al. 2019; Jacobsen et al. 2012; Jacobsen 2014). Depending on the variety, planting time, and specific field conditions and treatments, quinoa grain yields in other countries with Mediterranean conditions, such as Italy, are in the range between 1.5 and 3.4 t/ha (Lavini et al. 2014; Pulvento et al. 2010, 2012). In Romanian agro-climates, Danish quinoa breeding materials showed great potential for commercial cultivation, where Jacobsen 2 and Mixed Jacobsen had the highest seed yields (2.96 and 2.53 t/ha, respectively) and the harvest index than the other quinoa tested (Szilagyi and Jornsgard 2014).

Although there are no available data for quinoa cultivation in the European part of Turkey, cultivation in other parts in this country where the climate is similar to other Southeast European countries has been successful. Testing of the Titicaca variety in several field trials in Adana, part of Turkey, with a characteristic Mediterranean climate showed that seed yields varied from 1.69 to 2.12 t/ha (Yazar et al. 2015b). Also, testing the salt stress effect showed that grain yields were slightly reduced by saline irrigation compared to freshwater irrigation, with both yields ranging from 1.87 to 1.96 t/ha. A similar difference was observed for biomass yield, and these responses suggest a good adaptation of the Titicaca quinoa cultivar under these agroecological conditions (Yazar et al. 2015a). The good potential for quinoa as an alternative crop was also confirmed by a field study in the lowlands of the Eastern Anatolia region of Turkey (Tan and Temel 2018). In this study, a large number of cultivars were tested, and, as a result, there was a great variation in yield**.** Grain yields, of up to 4 t/ha, have been reported for the same quinoa cultivar, which is higher than in other studies conducted in different regions of Turkey. Also, it has been shown that variations in the yield were due to the differences in the locality in which the plants were grown.

The high tolerance of quinoa to arid conditions has also been tested in North Macedonia to identify the possibility of growing it as a new alternative crop. In field experiments with the Titicaca and Puno varieties at the Ovče Pole (as a particularly arid region in North Macedonia), an average yield of about 0.70 t/ha was observed in irrigated fields, twice as high as in rain-fed conditions (Bosev et al. 2007). Seeds from irrigated field have slightly higher protein and oil content than seeds from rain-fed conditions.

Table 16.1 Chemical characteristics and mineral composition of the quinoa seeds (cv. Puno). The values are expressed on the dry weight basis (modified from Stikic et al. 2012)

Content (%)	Quinoa whole seeds
Protein	17.41
Oil	4.79
Crude fiber	10.32
Ash	7.06
Starch	49.55
P (g kg^{-1})	2.40
Ca (g kg^{-1})	4.50
K (g kg^{-1})	9.52
Mg (g kg^{-1})	1.50
Fe (mg kg^{-1})	49.63
Cu (mg kg^{-1})	2.89
Zn (mg kg^{-1})	18.70
Mn (mg kg^{-1})	19.43

Table 16.2 Amino acid profile (g 100 g^{-1} protein) in purified Puno quinoa seeds (modified from Stikic et al. 2012 and Präger et al. 2018)

	References	
Essential amino acid	Stikic et al. (2012)	Präger et al. (2018)[a]
Thr	3.03	3.23
His	2.64	2.18
Tyr	3.63	2.34
Val	5.34	3.90
Met	2.16	1.65
Lys	3.91	4.47
Ile	5.00	3.20
Leu	8.29	5.48
Phe	4.69	3.52

[a] Data represent 2-year mean values

Danish cultivar Puno was the first for testing the possibility to grow in Serbian agroclimatic conditions during 2009 year (Stikic et al. 2012). Even in rain-fed and fertilizer-free conditions, seed yields of up to 1721 t/ha were obtained, while the quality of the seeds was extraordinarily good (Table 16.1), with high protein content and content of minerals.

The content of essential amino acids was also very high (Table 16.2) when compared to the results of Präger et al. (2018). These differences can be primarily attributed to specific agroecological conditions of growing Puno cultivar in these two experiments.

In addition to the lowland regions and growing plants at fertile chernozem soil, testing of quinoa cultivar Puno as an alternative grain was also done in the hilly and mountainous regions of Serbia. These results demonstrated that quinoa could be successfully grown in these conditions with a yield varying between 0.69 and 0.83 t/ha depending on locations and climatic conditions in 2009 and 2010 (Glamoclija et al. 2010). In the mountainous areas of Serbia, there are conditions for organic cultivation of different plants (especially fruits), so that with improved agro-technology for increasing yield, quinoa could be grown there even as organic culture. Quinoa in these areas could also be used to feed livestock, which is of particular importance because livestock farming is one of the basic agricultural activities in mountainous region in Serbia, and similarly in other SEE countries.

To test the possibility of growing different cultivars of quinoa in Serbia, the Titicaca cultivar was also included. These results did not show significant differences between investigated cultivars (unpublished data). Comparison between macro- and microstructures of grain (done by Raman and FTIR spectroscopy) also showed no significant differences in structure between Puno and Titicaca seeds as well as in their biochemical composition (crude protein and starch content). These results indicate that Raman spectroscopy as a relatively simple and inexpensive "in vivo" method is very useful for localization, quantification, and structural identification of stored reserves inside the seeds of different genotypes of quinoa (Czekus et al. 2019).

The market for quinoa is increasingly growing because a lot of consumers in Europe, as well as in SEE, recognized the need for healthy food and diet. Especially because both the FAO and EFSA (European Food Safety Authority) have proposed that quinoa, due to its favorable nutritional balance, be used to improve the nutrition of the world population, especially in less developed countries. The use of quinoa could be a challenge for an increasing bakery market. However, because of its low baking quality, which is due to the lack of gluten, quinoa flour can only partially substitute wheat flour in bread making or other baked products.

Our results have shown that wheat bread supplemented with quinoa seeds cultivated in Serbia could enable the development of a number of new baking products with increased nutritional values (Stikic et al. 2012). The nutritional value of wheat breads produced with the addition of 20% of Puno seeds had a much higher content of protein, oil, and fiber than wheat bread (Table 16.3). Additionally, sensory characteristics of evaluated quinoa breads were excellent. Also, the implementation of quinoa together with a buckwheat seeds at a 40% level increased the content of protein and fiber in supplemented bread (Demin et al. 2013). The addition of quinoa and buckwheat seeds also affected the rheological characteristics of dough and improved sensory characteristics of supplemented breads. Further studies showed that wheat flour supplemented with a mixture of quinoa, buckwheat, and pumpkin seeds was used to make a new type of bread and that the bread thus formed resulted in an increase in the protein, oil, and crude fiber content of the control, wheat bread (Table 16.3). Supplemented bread also had higher energy value, specific volume, and good sensory characteristics as aromatic odor and taste (Milovanović et al. 2014).

Results of Jaldani et al. (2018) also confirmed good nutritional and digestibility properties of quinoa flour, which makes it a suitable option for enrichment of bread formulation. Similarly, investigations of Ballester-Sánchez et al. (2019) confirmed that inclusion of flour obtained from three quinoa types (white, red, and black) improved the quality of the bakery products with respect to fatty acids such as

Table 16.3 Chemical characteristics of wheat breads and breads produced with the addition of purified quinoa seeds and other supplements. The values are expressed on the dry weight basis

	References	
	Stikic et al. (2012)	
Content (%)	Wheat bread	Bread + 20% quinoa
Protein	11.89	13.83
Oil	0.98	1.90
Crude fiber	0.60	1.71
Ash	2.98	2.60
Starch	70.25	67.36
	Demin et al. (2013)	
Content (%)	Wheat bread	Bread + 20% quinoa + 20% buckwheat
Protein	13.06	15.47
Oil	0.25	2.12
Crude fiber	0.50	0.91
Ash	3.98	3.35
Starch	71.45	67.60
	Milovanović et al. (2014)	
Content (%)	Wheat bread	Bread + 15% quinoa + 15% buckwheat + 10% pumpkin seed
Protein	11.21	17.27
Oil	0.85	4.69
Crude fiber	4.7	9.29
Ash	2.56	2.07
Starch	67.39	59.70

linoleic and linolenic acids, dietary fiber, Fe and Zn, protein quality, and a reduced glycemic index.

The quinoa market is largely driven by the increasing use in the food industry leading to the creation of new quinoa products. In the European and SEE markets, and especially in health food stores, there is an increase in number of food products, such as quinoa bakery, soups, sweets, pasta, noodles, breakfast cereals, baby food, etc. Because quinoa is regarded an alternative to meat, the price is very competitive. However, quinoa seeds in Southeast European countries are mainly imported and sold in health food stores, so the growth of quinoa market is still limited. Also, high quinoa prices, compared to other similar crops, limit its purchase from low-income households, as is the case in many Southeast European countries. If quinoa were grown commercially in the countries of Southeast Europe as an alternative and drought-resistant crop, its price will be lower and its consumption would increase. It is especially important that in addition to the agricultural market, the markets of the cosmetics, pharmaceutical, and pharmaceutical industries also use the nutritional value of quinoa, which will also affect the expansion of the quinoa cultivation area. Therefore, the cultivation of quinoa in the future could become economically very attractive for SEE region.

However, there are many different agroecological zones in the countries of SEE region, so it takes time to test the appropriate agro-technologies for quinoa cultivation, especially the time and rate of irrigation and fertilization, and to find the most suitable quinoa varieties for a particular region that will produce a good and stable yield. Training of farmers and other food producers in the successful cultivation of quinoa should also be organized, and efforts should be stepped up to promote and popularize quinoa production. This is still not done enough in the SEE region, although social networks, especially the Internet, are very intensively promoting the use of quinoa and its products as nutritionally valuable and health food.

The increasing emphasis on nutritional and health-promoting effects of quinoa, especially online, and the increasing presence in the market of quinoa seeds and its food products (both in classic and health food stores) have encouraged some local farmers in Serbia and Croatia to try to grow quinoa in an organized manner.

16.6 Conclusion and Future Prospects

In Europe, the southeastern region is particularly vulnerable to climate change. Climate change is projected to cause global warming in this region, resulting in increased temperatures, periods of drought, and the occurrence of increasingly frequent extreme climate change effects (heat waves, drought, floods, and storms). In such conditions, the agricultural production is very threatened. This is of particular importance because in many SEE countries, agriculture makes a significant contribution to their overall economy. Therefore, the challenge for the whole SEE region in the coming years will be to ensure that agricultural production is maintained at a level that will ensure optimal agriculture and food safety and sustainability.

Climate change responses include increasing the agricultural sector's adaptive capacity in the future and implementing appropriate measures at regional, national, and farm level. Adaptation measures at farm level are numerous, including the application of appropriate agronomic methodology (changing planting and harvesting times, use of stress-resistant crops and varieties, crop rotation, improved irrigation, fertilization techniques, etc.).

One of the possible approaches is also to introduce in agricultural production ancient crops resistant to stress factors, such as quinoa. Thanks to their unique properties (stress resistance, nutritional and health-giving characteristics) and the great interest of consumers, production of quinoa is expanding in the world. However, there is still no organized production of quinoa in the SEE countries, but the number of experiments in which it is being tested is increasing significantly. Testing the conditions of quinoa cultivation in individual localities (agrotechnical measures, especially nutrition and irrigation, as well as the selection of suitable varieties) will allow the area of its organized cultivation to extend to the specific SEE region and localities. Also, other necessary measures include the training of farmers and the agroindustry for whom quinoa is a new crop. State institutions could also assist with incentive measures for quinoa cultivation and the formation of quinoa producer associations.

Although the quinoa market in SEE countries is not as large as in other European countries, it is growing very intensively so that the food industry develops still more quinoa products. This will also lead to increasing economic effects, so the prospects for future quinoa production in SEE countries are promising.

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References

Abderrahim F, Huanatico E, Segura R, Arribas S, Gonzalez MC, Condezo-Hoyos L (2015) Physical features, phenolic compounds, betalains and total antioxidant capacity of coloured quinoa seeds (*Chenopodium quinoa* Willd.) from Peruvian Altiplano. Food Chem 183:83–90

Adolf VI, Shabala S, Andersen MN, Razzaghi F, Jacobsen S-E (2012) Varietal differences of quinoa's tolerance to saline conditions. Plant Soil 357:117–129

Adolf VI, Jacobsen S-E, Shabala S (2013) Salt tolerance mechanisms in quinoa (*Chenopodium quinoa* Willd.). Environ Exp Bot 92:43–54

Ahmadi SH, Solgi S, Sepaskhah AR (2019) Quinoa: a super or pseudo-super crop? Evidences from evapotranspiration, root growth, crop coefficients, and water productivity in a hot and semi-arid area under three planting densities. Agric Water Manag 225:105784

Alandia G, Jacobsen S-E, Kyvsgaard NC, Condori B, Liu F (2016) Nitrogen sustains seed yield of quinoa under intermediate drought. J Agron Crop Sci 202:281–291

Amjad M, Akhtar SS, Yang A, Akhtar J, Jacobsen S-E (2015) Antioxidative response of quinoa exposed to iso-osmotic, ionic and non-ionic salt stress. J Agron Crop Sci 201:452–460

Arneja I, Tanwar B, Chauhan A (2015) Nutritional composition and health benefits of golden grain of 21st century, quinoa (*Chenopodium quinoa* Willd.). A review. Pak J Nutr 14(12):1034–1040

Ballester-Sánchez J, Millán-Linares MC, Fernández-Espinar MT, Haros CM (2019) Development of healthy, nutritious bakery products by incorporation of quinoa. Foods 8(379):1–13

Bazile D, Baudron F (2015) The dynamics of the global expansion of quinoa growing in view of its high biodiversity. In: Bazile D, Bertero HD, Nieto C (eds) State of the art report on quinoa around the world in 2013. FAO & CIRAD, Roma, pp 42–55

Bazile D, Bertero HD, Nieto C (eds) (2015) State of the art report on quinoa around the world in 2013. FAO & CIRAD, Roma

Bazile D, Jacobsen S-E, Verniau A (2016) The global expansion of quinoa: trends and limits. Front Plant Sci 7:622.1–622.6

Becker VI, Goessling JW, Duarte B, Cacador I, Liu F, Rosenqvist E, Jacobsen S-E (2017) Combined effects of soil salinity and high temperature on photosynthesis and growth of quinoa plants (*Chenopodium quinoa* Willd.). Funct Plant Biol 44:665–678

Bhargava A, Shukla S, Srivastava J, Singh N, Ohri D (2008) Chenopodium: a prospective plant for phytoextraction. Acta Physiol Plant 30:111–120

Bilalis DJ, Roussis I, Kakabouki I, Folina A (2019) Quinoa (*Chenopodium quinoa* Willd.) crop under Mediterranean conditions: a review. Cien Invest Agr 46(2):51–68

Bisselink B, Benhard J, Gelati E, Adamovic M, Guenther S, Mentaschi L, De Roo A (2018) Impact of a changing climate, land use, and water usage on Europe's water resources. A model simulation study, Report No JRC110927, Publications Office of the European Union, Luxembourg. https://doi.org/10.2760/847068

Blanco M, Ramos F, Doorslaer BV, Martínez P, Fumagalli D, Ceglar A, Fernández FJ (2017) Climate change impacts on EU agriculture: a regionalized perspective taking into account market-driven adjustments. Agric Syst 156:52–66

Bonales-Alatorre E, Pottosin I, Shabala L, Chen ZH, Zeng F, Jacobsen S-E, Shabala S (2013) Differential activity of plasma and vacuolar membrane transporters contributes to genotypic differences in salinity tolerance in a halophyte species, *Chenopodium quinoa*. Int J Mol Sci 14:9267–9285

Bosev D, Vasilevski G, Peshevski M, Shekerinov D, Vasilevski N, Jovanov D, Jacobsen S-E, Quarrie S (2007) Potential for quinoa (*Chenopodium quinoa* Willd.) production in Ovce Pole region. In: Proceedings of the conference water productivity in agriculture and horticulture: how can less water be used more efficiently? Faculty of Life Sciences, University of Copenhagen, Copenhagen, Denmark, 2-4 July 2007, p 10

Campbell BM, Vermeulen SJ, Aggarwal PK, Corner-Dolloff C, Girvetz E, Loboguerrero AM, Ramirez-Villegas J, Rosenstock T, Sebastian L, Thornton PK, Wollenberg E (2016) Reducing risks to food security from climate change. Glob Food Sec 11:34–43

Ceglar A, Zampieri M, Toreti A, Dentener F (2019) Observed northward migration of agro-climate zones in Europe will further accelerate under climate change. Earth's Future 7:1088–1101

Cheval S, Dumitrescu A, Birsan M-V (2017) Variability of the aridity in the South-Eastern Europe over 1961–2050. Catena 151:74–86

Ciscar JC, Ibarreta D, Soria A, Dosio A, Toreti A, Ceglar A, Fumagalli D, Dentener F, Lecerf R, Zucchini A, Panarello A, Niemeyer S, Pérez-Domínguez I, Fellmann T, Kitous A, Després J, Christodoulou A, Demirel H, Alfieri L, Dottori F, Vousdoukas MI, Mentaschi L, Voukouvalas L, Cammalleri C, Barbosa P, Micale F, Vogt JV, Barredo JI, Caudullo G, Mauri A, de Rigo D, Libertà G, Houston Durrant T, Artés Vivancos T, San-Miguel-Ayanz J, Gosling SN, Zaherpour J, De Roo A, Bisselink B, Bernhard J, Bianchi L, Rozsai M, Szewczyk W, Mongelli I, Feyen L (2018) Climate impacts in Europe: final report of the JRC PESETA III project, JRC112769. Publications Office of the European Union, Luxembourg. https://doi.org/10.2760/93257

Cocozza C, Pulvento C, Lavini A, Riccardi M, d'Andria R, Tognetti R (2012) Effects of increasing salinity stress and decreasing water availability on ecophysiological traits of quinoa (*Chenopodium quinoa* Willd.) grown in a Mediterranean. J Agron Crop Sci 199:229–240

Czekus B, Pećinar I, Petrović I, Paunović N, Savić S, Jovanović Z, Stikić R (2019) Raman and Fourier transform infrared spectroscopy application to the Puno and Titicaca cvs. of quinoa seed microstructure and perisperm characterization. J Cereal Sci 87:25–30

Demin MA, Vucelić-Radović BV, Banjac NR, Tipsina NN, Milovanović MM (2013) Buckwheat and quinoa seeds as supplements in wheat bread production. Hem Ind 67:115–121

Donatelli M, Srivastava AK, Duveiller G, Niemeyer S (2012) Estimating impact assessment and adaptation strategies under climate change scenarios for crops at EU27 scale. In: Proceedings of the international congress on environmental modelling and software "managing resources of a limited planet: pathways and visions under uncertainty", Leipzig, Germany, 1–5 July 2012, pp 404–411

EEA (2015) Climate change impacts and adaptation. http://www.eea.europa.eu/soer-2015/europe/climate-change-impacts-and-adaptation

EEA (2017) Climate change, impacts and vulnerability in Europe 2016—an indicator-based report, EEA Report No 1/2017. https://www.eea.europa.eu/publications/climate-change-impacts-and-vulnerability-2016

EEA (2019) Report No 4/2019 Climate change adaptation in the agriculture sector in Europe. https://www.eea.europa.eu/publications/cc-adaptation-agriculture

FAO (2011) Quinoa: an ancient crop to contribute to world food security. http://www.fao.org/3/aq287e/aq287e.pdf

FAO (2013a) The International Year of Quinoa. http://www.fao.org/quinoa-2013/

FAO (2013b) Climate-smart agriculture sourcebook. http://www.fao.org/3/a-i3325e.pdf

FAO (2016) Climate change and food security: risks and responses, FAO No 1/2016, Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/3/a-i5188e.pdf

FAO (2018) Drought risk management guidelines Western Balkan region. http://www.fao.org/3/i9148en/I9148EN.pdf

Fgire R, Issa Ali O, Anaya F, Benlhabib O, Jacobsen S-E, Wahb S (2013) Protective antioxidant enzyme activities are affected by drought in quinoa. J Biol Agric Healthc 3:62–68

Fuentes F, Bazile D, Bhargava A, Martinez EA (2012) Implications of farmers' seed exchanges for on-farm conservation of quinoa, as revealed by its genetic diversity in Chile. J Agric Sci 150:702–716

García M, Raes D, Jacobsen S-E (2003) Evapotranspiration analysis and irrigation requirements of quinoa (*Chenopodium quinoa*) in the Bolivian highlands. Agric Water Manag 60:119–134

García M, Raes D, Jacobsen S-E, Michel T (2007) Agroclimatic constraints to rainfed agriculture in the Bolivian Altiplano. J Arid Environ 71:109–121

Gawlik-Dziki U, Swieca M, Sułkowski M, Dziki D, Baraniak B, Czyz J (2013) Antioxidant and anticancer activities of *Chenopodium quinoa* leaves extracts—in vitro study. Food Chem Toxicol 57:154–160

Geerts S, Raes D, Garcia M, Vacher J, Mamani R, Mendoza J, Huanca R, Morales B, Miranda R, Cusicanqui J, Taboada C (2008) Introducing deficit irrigation to stabilize yields of quinoa (*Chenopodium quinoa* Willd.). Eur J Agron 28:427–436

Geerts S, Raes D, Garcia M, Taboada C, Miranda R, Cusicanqui J, Mhizha T, Vacher J (2009) Modeling the potential for closing quinoa yield gaps under varying water availability in the Bolivian Altiplano. Agric Water Manag 96:1652–1658

Georgopoulou E, Mirasgedis S, Sarafidis Y, Vitaliotou M, Lalas DP, Theloudis I, Giannoulaki K-D, Dimopoulos D, Zavras V (2017) Climate change impacts and adaptation options for the Greek agriculture in 2021–2050: a monetary assessment. Clim Risk Manag 16:164–182

Geren H (2015) Effects of different nitrogen levels on the grain yield and some yield components of quinoa (*Chenopodium quinoa* Willd.) under Mediterranean climatic conditions. Turk J Field Crops 20:59–64

Glamoclija DJ, Staletic M, Ikanovic J, Spasic M, Djekic V, Davidovic M (2010) Possibilities alternative grain production in the highlands area of Central Serbia. Econ Agric 57(2):71–77

González JA, Bruno M, Valoy M, Prado FE (2011) Genotypic variation of gas exchange parameters and leaf stable carbon and nitrogen isotopes in ten quinoa cultivars grown under drought. J Agron Crop Sci 197:81–93

Gordillo-Bastidas E, Díaz-Rizzolo DA, Roura E, Massanés T, Gomis R (2016) Quinoa (*Chenopodium quinoa* Willd), from nutritional value to potential health benefits: an integrative review. J Nutr Food Sci 6:497, 1–10

Graf BL, Poulev A, Kuhn P, Grace M, Lila MA, Raskin I (2014) Quinoa seeds leach phytochemicals and other compounds with anti-diabetic properties. Food Chem 163:178–185

Graf BL, Rojas-Silva P, Rojo LE, Delatorre-Herrera J, Baldeon ME, Raskin I (2015) Innovations in health value and functional food development of quinoa (*Chenopodium quinoa* Willd.). Compr Rev Food Sci Food Saf 14:431–445

Hariadi Y, Marandon K, Tian Y, Jacobsen S-E, Shabala S (2011) Ionic and osmotic relations in quinoa (*Chenopodium quinoa* Willd.) plants grown at various salinity levels. J Exp Bot 62 (1):185–193

Haseeb M, Basra SMA, Afzal I, Wahid A (2018) Quinoa response to lead: growth and lead partitioning. Int J Agric Biol 20:338–344

Hernández-Ledesma B (2019) Quinoa (*Chenopodium quinoa* Willd.) as a source of nutrients and bioactive compounds: a review. Bioact Compds Health Dis 2(3):27–47

Hinojosa L, González JA, Barrios-Masias FH, Fuentes F, Murphy KM (2018) Quinoa abiotic stress responses: a review. Plants 7:106, 1–32

Hirich A, Choukr-Allah R, Jacobsen S-E (2014a) The combined effect of deficit irrigation by treated wastewater and organic amendment on quinoa (*Chenopodium quinoa* Willd.) productivity. Desalination Water Treat 52:2208–2213

Hirich A, Choukr-Allah R, Jacobsen S-E (2014b) Deficit irrigation and organic compost improve growth and yield of quinoa and pea. J Agron Crop Sci 200:390–398

Hu Y, Zhang J, Zou L, Fu C, Li L, Zhao G (2017) Chemical characterization, antioxidant, immune-regulating and anticancer activities of a novel bioactive polysaccharide from *Chenopodium quinoa* seeds. Int J Biol Macromol 99:622–629

Iliadis C, Karyotis T, Jacobsen S-E (2001). Adaptation of quinoa under xerothermic conditions and cultivation for biomass and fibre production. In: Jacobsen S-E, Portillo Z (eds) Memorias, Primer Taller Internacionalsobre Quinua—Recursos Geneticos y Sistemasde Producción, UNALM, International Potato Lima, Peru 10–14 May 1999, pp 371–378

IPCC (2013) Long-term Climate Change: projections, Commitments and Irreversibility. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Climate change 2013: the physical science basis. Contribution of working group i to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

IPCC (2018) Global warming of 1.5 °C, Intergovernmental Panel on Climate Change, Geneva, Switzerland. http://www.ipcc.ch/report/sr15/

IPCC (2019) Climate change and land. Summary for policy makers, intergovernmental panel on climate change, Geneva, Switzerland. https://www.ipcc.ch/site/assets/uploads/2019/08/4.-SPM_Approved_Microsite_FINAL.pdf

Iqbal S, Basra SMA, Afzal I, Wahid A, Saddiq MS, Hafeez MB, Jacobsen S-E (2019) Yield potential and salt tolerance of quinoa on salt-degraded soils of Pakistan. J Agron Crop Sci 205:13–21

Ismail H, Maksimović JD, Maksimović V, Shabala L, Živanović BD, Tian Y, Jacobsen S-E, Shabala S (2016) Rutin, a flavonoid with antioxidant activity, improves plant salinity tolerance by regulating K^+ retention and Na^+ exclusion from leaf mesophyll in quinoa and broad beans. Funct Plant Biol 43:75–86

Izquierdo J, Mujica A, Marathee JP, Jacobsen S-E (2003) Horizontal, technical cooperation in research on quinoa (*Chenopodium quinoa* Willd.). Food Rev Int 19:25–29

Jacobsen S-E (2003) The worldwide potential for quinoa (*Chenopodium quinoa* Willd.). Food Rev Int 19:167–177

Jacobsen S-E (2011) The situation for quinoa and its production in Southern Bolivia: from economic success to environmental disaster. J Agron Crop Sci 197:390–399

Jacobsen S-E (2014) New climate proof cropping systems in dry areas of the Mediterranean region. J Agron Crop Sci 200:399–401

Jacobsen S-E (2017) The scope for adaptation of quinoa in Northern Latitudes of Europe. J Agron Crop Sci 203:603–613

Jacobsen S-E, Mujica A (2003) Quinoa: an alternative crop for saline soils. In: Proceedings of the international conference on water-saving agriculture and sustainable use of water and land resources (ICWSAWLR). Yangling, Shaanixi, China. 26-29 October 2003. J Exp Bot 54:i25

Jacobsen S-E, Mujica A, Jensen CR (2003) The resistance of quinoa (*Chenopodium quinoa* Willd.) to adverse abiotic factors. Food Rev Int 19(1&2):99–109

Jacobsen S-E, Monteros C, Christiansen JL, Bravo LA, Corcuera LJ, Mujica A (2005) Plant responses of quinoa (*Chenopodium quinoa* Willd.) to frost at various phenological stages. Eur J Agron 22:131–139

Jacobsen S-E, Monteros C, Corcuera LJ, Bravo LA, Christiansen JL, Mujica A (2007) Frost resistance mechanisms in quinoa (*Chenopodium quinoa* Willd.). Eur J Agron 26:471–475

Jacobsen S-E, Liu F, Jensen CR (2009) Does root-sourced ABA play a role for regulation of stomata under drought in quinoa (*Chenopodium quinoa* Willd.). Sci Hortic 122:281–287

Jacobsen S-E, Jensen CR, Liu F (2012) Improving crop production in the arid Mediterranean climate. Field Crops Res 128:34–47

Jacobsen S-E, Sørensen M, Pedersen SM, Weiner J (2013) Feeding the world: genetically modified crops versus agricultural biodiversity. Agron Sustain Dev 33:651–662

Jacobsen S-E, Sørensen M, Pedersen SM, Weiner J (2015) Using our agrobiodiversity: plant-based solutions to feed the world. Agron Sustain Dev 35:1217–1235

Jaikishun S, Li W, Yang Z, Song S (2019) Quinoa: in perspective of global challenges. Agronomy 9:176, 1–15

Jaldani S, Nasehi B, Barzegar H, Sepahvand N (2018) Optimization of physical and imaging properties of flat bread enriched with quinoa flour. Nutr Food Sci Res 5:25–34

Jarvis DE, Ho YS, Lightfoot DJ, Schmöckel SM, Li B, Borm TJ, Ohyanagi H, Mineta K, Michell CT, Saber N, Kharbatia NM, Rupper RR, Sharp AR, Dally N, Boughton BA, Woo YH, Gao G, Schijlen EG, Guo X, Momin AA, Negrão S, Al-Babili S, Gehring C, Roessner U, Jung C, Murphy K, Arold ST, Gojobori T, Linden CG, van Loo EN, Jellen EN, Maughan PJ, Tester M (2017) The genome of *Chenopodium quinoa*. Nature 542:307–312

Jensen CR, Jacobsen S-E, Andersen MN, Núñez N, Andersen SD, Rasmussen L, Mogensen VO (2000) Leaf gas exchange and water relations of field quinoa (*Chenopodium quinoa* Willd.) during soil drying. Eur J Agron 13:11–25

Karyotis T, Iliadis C, Noulas C, Mitsibonas T (2003) Preliminary research on seed production and nutrient content for certain quinoa varieties in a saline–sodic soil. J Agron Crop Sci 189:402–408

King M, Altdorff D, Li P, Galagedara L, Holden J, Unc A (2018) Northward shift of the agricultural climate zone under 21st century global climate change. Sci Rep 8:1–10

Lavini A, Pulvento C, d'Andria R, Riccardi M, Choukr-Allah R, Belhabib O, Yazar A, Ince Kaya Ç, Sezen SM, Qadir M, Jacobsen S-E (2014) Quinoa's potential in the Mediterranean Region. J Agron Crop Sci 200:344–360

Lavini A, Pulvento C, d'Andria R, Riccardi M, Jacobsen S-E (2016) Effects of saline irrigation on yield and qualitative characterization of seed of an amaranth accession grown under Mediterranean conditions. J Agric Sci 154:858–869

Lipper L, Thornton P, Campbell BM, Baedeker T, Braimoh A, Bwalya M, Caron P, Cattaneo A, Garrity D, Henry K, Hottle R, Jackson L, Jarvis A, Kossam F, Mann W, McCarthy N, Meybeck A, Neufeldt H, Remington T, Sen PT, Sessa R, Shula R, Tibu A, Torquebiau EF (2014) Climate-smart agriculture for food security. Nat Clim Change 4:1068–1072

Liu J, Wang R, Liu W, Zhang H, Guo Y, Wen R (2018) Genome-wide characterization of heat-shock protein70s from *Chenopodium quinoa* and expression analyses of Cqhsp70s in response to drought stress. Genes 9:35, 1–15

Lutz M, Bascuñán-Godoy L (2017) The revival of quinoa: a crop for health. In: Waisundara V, Shiomi N (eds) Superfood and functional food—an overview of their processing and utilization. IntechOpen. https://doi.org/10.5772/65451

Maradini-Filho AM (2017) Quinoa: nutritional aspects. J Nutraceut Food Sci 2:3

Mavromatis T (2015) Crop–climate relationships of cereals in Greece and the impacts of recent 6 climate trends. Theor Appl Climatol 120:417–432

Mihailović DT, Lalić B, Drešković N, Mimić G, Djurdjević V, Jančić M (2015) Climate change effects on crop yields in Serbia and related shifts of Köppen climate zones under the SRES-A1B and SRES-A2. Int J Climatol 35:3320–3334

Milovanović MM, Demin MA, Vucelić-Radović BV, Zarković BM, Stikić RI (2014) Evaluation of the nutritional quality of wheat bread prepared with quinoa, buckwheat and pumpkin seed blends. J Agric Sci 59:319–328

Morales A, Zurita-Silva A, Maldonado J, Silva H (2017) Transcriptional responses of Chilean quinoa (*Chenopodium quinoa* Willd.) under water deficit conditions uncovers ABA-independent expression patterns. Front Plant Sci 8:216, 1–13

Nanduri KR, Hirich A, Salehi M, Saadat S, Jacobsen S-E (2019) Quinoa: a new crop for harsh environments. In: Gul B, Böer B, Khan M, Clüsener-Godt M, Hameed A (eds) Sabkha ecosystems. Tasks for vegetation science VI. Tasks for vegetation science, vol 49. Springer Nature Switzerland, Cham, pp 331–333

Navruz-Varli S, Sanlier N (2016) Nutritional and health benefits of quinoa (*Chenopodium quinoa* Willd.). J Cereal Sci 69:371–376

Noulas C, Tziouvalekas M, Vlachostergios D, Baxevanos D, Karyotis T, Iliadis C (2017) Adaptation, agronomic potential, and current perspectives of quinoa under Mediterranean conditions: case studies from the lowlands of Central Greece. Commun Soil Sci Plant Anal 48:2612–2629

Nowak R, Szewczyk K, Gawlik-Dziki U, Rzymowska J, Komsta L (2016) Antioxidative and cytotoxic potential of some *Chenopodium* L. species growing in Poland. Saudi J Biol Sci 23:15–23

OECD (2018) Agriculture in South East Europe, in competitiveness in South East Europe: a policy outlook 2018. OECD Publishing, Paris. https://doi.org/10.1787/9789264298576-19-en

Olesen JE, Trnka M, Kersebaum KC, Skjelvåg AO, Seguin B, Peltonen-Sainio P, Rossi F, Kozyra J, Micale F (2011) Impacts and adaptation of European crop production systems to climate change. Eur J Agron 34:96–112

Panuccio MR, Jacobsen SE, Akhtar SS, Muscolo A (2014) Effect of saline water on seed germination and early seedling growth of the halophyte quinoa. AoB Plants 6:plu047

Paśko P, Tyszka-Czochara M, Namieśnik J, Jastrzębski Z, Leontowicz H, Drzewiecki J, Martinez-Ayala AL, Nemirovski A, Barasch D, Gorinstein S (2019) Cytotoxic, antioxidant and binding properties of polyphenols from the selected gluten-free pseudocereals and their by-products: *in vitro* model. J Cereal Sci 87:325–333

Peñas E, Uberti F, di Lorenzo C, Ballabio C, Brandolini A, Restani P (2014) Biochemical and immunochemical evidences supporting the inclusion of quinoa (*Chenopodium quinoa* Willd.) as a gluten-free ingredient. Plant Foods Hum Nutr 69:297–303

Präger A, Munz S, Nkebiwe PM, Mast B, Graeff-Hönning S (2018) Yield and quality characteristics of different quinoa (*Chenopodium quinoa* Willd.) cultivars grown under field conditions in Southwestern Germany. Agronomy 8:197, 1–19. https://doi.org/10.3390/agronomy8100197

Pulvento C, Riccardi M, Lavini A, D'andria R, Iafelice G, Marconi E (2010) Field trial evaluation of two *Chenopodium quinoa's* genotypes grown in rainfed conditions in a Mediterranean environment of South Italy. J Agron Crop Sci 197:407–411

Pulvento C, Riccardi M, Lavini A, Iafelice G, Marconi E, d'Andria R (2012) Yield and quality characteristics of quinoa grown in open field under different saline and non-saline irrigation regimes. J Agron Crop Sci 198:254–263

Ray DK, West PC, Clark M, Gerber JS, Prishchepov AV, Chatterjee S (2019) Climate change has likely already affected global food production. PLoS One 14(5):e0217148. https://doi.org/10.1371/journal.pone.0217148

Raza A, Razzaq A, Mehmood SS, Zou X, Zhang X, Lv Y, Xu J (2019) Impact of climate change on crops adaptation and strategies to tackle its outcome: a review. Plants 8:34, 1–29

Razzaghi F, Ahmadi SH, Adolf VI, Jensen CR, Jacobsen S-E, Andersen MN (2011) Water relations and transpiration of quinoa (*Chenopodium quinoa* Willd.) under salinity and soil drying. J Agron Crop Sci 197:348–360

Razzaghi F, Ahmadi SH, Jacobsen S-E, Jensen CR, Andersen MN (2012a) Effects of salinity and soil–drying on radiation use efficiency, water productivity and yield of quinoa (*Chenopodium quinoa* Willd.). J Agron Crop Sci 198:173–184

Razzaghi F, Plauborg F, Jacobsen S-E, Jensen CR, Andersen MN (2012b) Effect of nitrogen and water availability of three soil types on yield, radiation use efficiency and evapotranspiration in field-grown quinoa. Agric Water Manag 109:20–29

Razzaghi F, Jacobsen S-E, Jensen CR, Andersen MN (2015) Ionic and photosynthetic homeostasis in quinoa challenged by salinity and drought–mechanisms of tolerance. Funct Plant Biol 42:136–148

Repo-Carrasco R, Espinoza C, Jacobsen S-E (2003) Nutritional value and use of the Andean crops quinoa (*Chenopodium quinoa*) and kañiwa (*Chenopodium pallidicaule*). Food Rev Int 19:179–189

Repo-Carrasco-Valencia R, Hellström JK, Pihlava J-M, Mattila PH (2010) Flavonoids and other phenolic compounds in Andean indigenous grains: quinoa (*Chenopodium quinoa*), Kañiwa (*Chenopodium pallidicaule*) and Kiwicha (*Amaranthus caudatus*). Food Chem 120:128–133

Riccardi M, Pulvento C, Lavini A, d'Andria R, Jacobsen S-E (2014) Growth and ionic content of quinoa under saline irrigation. J Agron Crop Sci 200:246–260

Rojas W, Pinto M, Alanoca C, Gomez Pando L, Leon-Lobos P, Alercia A, Diulgheroff S, Padulosi S, Bazile D (2015). Quinoa genetic resources and ex situ conservation. In: Bazile D, Bertero HD, Nieto C (ed) State of the art report on quinoa around the world in 2013. Roma: FAO&CIRAD, pp 56–82

Ruiz KB, Biondi S, Oses R, Acuña-Rodríguez IS, Antognoni F, Martinez-Mosqueira EA, Coulibaly A, Canahua-Murillo A, Pinto M, Zurita-Silva A, Bazile D, Jacobsen S-E, Molina-Montenegro MA (2014) Quinoa biodiversity and sustainability for food security under climate change. A review. Agron Sustain Dev 34:349–359

Ruiz KB, Biondi S, Martínez EA, Orsini F, Antognoni F, Jacobsen S-E (2015) Quinoa—a model crop for understanding salt-tolerance mechanisms in halophytes. Plant Biosyst 150:357–371

Ruiz KB, Cicatelli A, Guarino F, Jacobsen S-E, Biondi S, Castiglione S (2017a) Can quinoa, a salt-tolerant Andean crop species, be used for phytoremediation of chromium-polluted soil? In: Proceedings of 19th EGU General Assembly, EGU2017, Vienna, Austria, 23-28 April 2017. Geophys Res Abstr 19:1069

Ruiz KB, Khakimov B, Engelsen SB, Bak S, Biondi S, Jacobsen S-E (2017b) Quinoa seed coats as an expanding and sustainable source of bioactive compounds: an investigation of genotypic diversity in saponin profiles. Ind Crop Prod 104:156–163

Ruiz KB, Rapparini F, Bertazza G, Silva H, Torrigiani P, Biondi S (2017c) Comparing salt-induced responses at the transcript level in a salares and coastal-lowlands landrace of quinoa (*Chenopodium quinoa* Willd.). Environ Exp Bot 139:127–142

Shabala L, Mackay A, Tian Y, Jacobsen S-E, Zhou D, Shabala S (2012) Oxidative stress protection and stomatal patterning as components of salinity tolerance mechanism in quinoa (*Chenopodium quinoa*). Physiol Plant 146:26–38

Shabala S, Hariadi Y, Jacobsen S-E (2013) Genotypic difference in salinity tolerance in quinoa is determined by differential control of xylem Na^+ loading and stomatal density. J Plant Physiol 170:906–914

Spinoni J, Vogt JV, Naumann G, Barbosa P, Dosio A (2018) Will drought events become more frequent and severe in Europe? Int J Climatol 38:1718–1736

Stikic R, Glamoclija DJ, Demin M, Vucelic-Radovic B, Jovanovic Z, Milojkovic-Opsenica D, Jacobsen S-E, Milovanovic M (2012) Agronomical and nutritional evaluation of quinoa seeds (*Chenopodium quinoa* Willd.) as an ingredient in bread formulations. J Cereal Sci 55:132–138

Stikić RI, Milinčić DD, Kostić AŽ, Jovanović ZB, Gašić UM, Tešić ŽL, Djordjević NZ, Savić SK, Czekus BG, Pešić MB (2020) Polyphenolic profiles, antioxidant, and *in vitro* anticancer activities of the seeds of Puno and Titicaca quinoa cultivars. Cereal Chem 97:626–633

Sun Y, Liu F, Bendevis M, Shabala S, Jacobsen S-E (2014) Sensitivity of two quinoa (*Chenopodium quinoa* Willd.) varieties to progressive drought stress. J Agron Crop Sci 200:12–23

Sun Y, Lindberg S, Shabala L, Morgan S, Shabala S, Jacobsen S-E (2017) A comparative analysis of cytosolic Na^+ changes under salinity between halophyte quinoa (*Chenopodium quinoa*) and glycophyte pea (*Pisum sativum*). Environ Exp Bot 141:154–160

Supit I, van Diepen CA, de Wit AJW, Wolf J, Kabat P, Baruth B, Ludwig F (2012) Assessing climate change effects on European crop yields using the Crop Growth Monitoring System and a weather generator. Agric For Meteorol 164:96–111

Szilagyi L, Jornsgard B (2014) Preliminary agronomic evaluation of *Chenopodium quinoa* Willd. In: Under climatic conditions of Romania series A agronomy LVII. pp 339–343

Tan M, Temel S (2018) Performance of some quinoa (*Chenopodium quinoa* Willd.) genotypes grown in different climate conditions. Turk J Field Crops 23:180–186

Tang Y, Tsao R (2017) Phytochemicals in quinoa and amaranth grains and their antioxidant, anti-inflammatory, and potential health. Mol Nutr Food Res 61:1600767. https://doi.org/10.1002/mnfr.201600767

Tang Y, Li X, Zhang B, Chen PX, Liu R, Tsao R (2015) Characterisation of phenolics, betanins and antioxidant activities in seeds of three *Chenopodium quinoa* Willd. genotypes. Food Chem 166:380–388

The Global Economy. https://www.theglobaleconomy.com/rankings/share_of_agriculture/Europe/

The World Bank Climate Change Knowledge Portal. https://climateknowledgeportal.worldbank.org/country/greece/climate-data-projections/

USAID (2017) Climate risk profile Serbia. https://www.climatelinks.org/sites/default/files/asset/document/2017_USAID_Climate%20Change%20Risk%20Profile_Serbia.pdf

Vega-Galvez A, Miranda M, Vergara J, Uribe E, Puente L, Martinez EA (2010) Nutrition facts and functional potential of quinoa (*Chenopodium quinoa* Willd.), an ancient Andean grain: a review. J Sci Food Agric 90:2541–2547

Vilcacundo R, Hernández-Ledesma B (2017) Nutritional and biological value of quinoa (*Chenopodium quinoa* Willd.). Curr Opin Food Sci 14:1–6

Vilcacundo R, Miralles B, Carrillo W, Hernández-Ledesma B (2018) In vitro chemopreventive properties of peptides released from quinoa (*Chenopodium quinoa* Willd.) protein under simulated gastrointestinal digestion. Food Res Int 105:403–411

Vuković AJ, Vujadinović MP, Rendulić SM, Đurđević VS, Ruml MM, Babić VP, Popović DP (2018) Global warming impact on climate change in Serbia for the period 1961-2100. Therm Sci 22:2267–2280

Wheeler T, von Braun J (2013) Climate change impacts on global food security. Science 341 (6145):508–513

Wiebe K, Robinson S, Andrea C (2019) Chapter 4: Climate change, agriculture and food security: impacts and the potential for adaptation and mitigation. In: Clayton C, Shivaji P (eds) Sustainable food and agriculture: an integrated approach. Academic, pp 55–74

WMO (2019) The global climate in 2015–2019. https://library.wmo.int/doc_num.php?explnum_id=9936

Yang A, Akhtar SS, Amjad M, Iqbal S, Jacobsen S-E (2016a) Growth and physiological responses of quinoa to drought and temperature stress. J Agron Crop Sci 202:445–453

Yang A, Akhtar SS, Iqbal S, Amjad M, Naveed M, Zahir ZA, Jacobsen S-E (2016b) Enhancing salt tolerance in quinoa by halotolerant bacterial inoculation. Funct Plant Biol 43:632–642

Yang A, Akhtar SS, Iqbal S, Qi Z, Alandia G, Saddiq MS, Jacobsen S-E (2017) Saponin seed priming improves salt tolerance in quinoa. J Agron Crop Sci 204:31–39

Yao Y, Shi Z, Ren G (2014) Antioxidant and immunoregulatory activity of polysaccharides from quinoa (*Chenopodium quinoa* Willd.). Int J Mol Sci 15:19307–19318

Yazar A, Ince Kaya C (2014) A new crop for salt affected and dry agricultural areas of Turkey: quinoa (*Chenopodium quinoa* Willd.). Türkjans 2:1440–1446

Yazar A, Ince Kaya C, Sezen MS, Jacobsen S-E (2015a) Saline water irrigation of quinoa (*Chenopodium quinoa*) under Mediterranean conditions. Crop Pasture Sci 66:993–1002

Yazar A, Ince Kaya C, Sezen MS, Tekin S (2015b) Quinoa experimentation and production in Turkey. In: Bazile D, Bertero HD, Nieto C (eds) State of the art report on quinoa around the world in 2013. Roma, FAO & CIRAD, pp 466–477

Zurita-Silva A, Jacobsen S, Razzaghi F, Álvarez Flores R, Ruiz K, Morales A, Silva Ascencio H (2015) Quinoa drought responses and adaptation. In: Bazile D, Bertero HD, Nieto C (eds) State of the art report on quinoa around the world in 2013. Roma, FAO & CIRAD, pp 157–171