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A New Crop for Salt Affected and Dry Agricultural Areas of Turkey: Quinoa (*Chenopodium quinoa* Willd.)

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Abstract

Drought and salinity are two widespread environmental problems induced by climate change and improper applications in agriculture and have important adverse effects on agricultural production. To sustain crop production in such areas for food security, cultivating new crops that can growth under these unfavorable conditions is one of the measures. Quinoa (*Chenopodium quinoa* Willd.) is an annual grain plant originated from the Andean region of South America. This plant has potential to be an alternative crop for arid and salt affected agricultural lands or poor soils with its ability to tolerate various abiotic stress factors and adaptability to different environmental conditions. Its high gluten free nutritional component is another characteristic that makes quinoa an important crop for human diets. In this study, quinoa was introduced as a new crop for Turkey and cultivation possibilities of quinoa in arid and salt affected areas of the country was evaluated in the light of the research carried out in Cukurova University between the years of 2009 and 2012. According to this research results quinoa could cope with high salinity in the root zone up to 40 dS m^{-1} of electrical conductivity of irrigation water, which many other crops couldn't tolerate this salinity level. In conclusion, quinoa may be suggested as an alternative crop for marginal agricultural areas thanks to its stress tolerant characteristic, adaptability to different agro-environmental conditions with its various cultivars can be grown from sea level to highlands, nutritional component and economic value.

Keywords: Quinoa, drought and salinity stress, irrigation water quality, deficit irrigation

Türkiye Tuzlu ve Kuru Tarım Alanları için Yeni Bir Bitki: Quinoa (*Chenopodium quinoa* Willd.)

Özet

Kuraklık ve tuzluluk, hatalı tarımsal uygulamalar ve iklim değişikliği ile tetiklenen iki yaygın çevresel problemdir ve tarımsal üretimi olumsuz etkilemektedir. Bu gibi alanlarda tarımsal üretimin sürdürülebilmesi için söz konusu elverişsiz koşullarda gelişebilen yeni bitkilerin yetiştirilmesi alınabilecek önlemlerden birisidir. Quinoa (*Chenopodium quinoa* Willd.) anavatanı Güney Amerika'nın And bölgesi olan tek yıllık bir dane bitkisidir. Bu bitki çeşitli abiyotik stres faktörlerini tolere edebilme becerisi ve farklı çevresel koşullara uyum yeteneği ile kurak ve tuzdan etkilenmiş tarım alanları ya da verimsiz topraklar için alternatif bir ürün olma potansiyeline sahiptir. Glütensiz zengin besin içeriği quinoa bitkisini insan beslenmesi açısından önemli kılan bir başka özelliğidir. Bu çalışmada, Türkiye için yeni bir ürün olarak quinoa bitkisi tanıtılmış ve 2009-2012 yılları arasında Çukurova Üniversitesinde yürütülen araştırma ışığında, ülkenin kurak ve tuzdan etkilenmiş alanlarında quinoa bitkisinin yetiştirilme olanakları değerlendirilmiştir. Araştırma sonuçlarına göre quinoa bitkisi sulama suyu elektriksel iletkenliği 40 dS m^{-1} düzeyine kadar, diğer birçok bitkinin tolere edemediği kök bölgesindeki yüksek tuzluluk ile baş edebilmiştir. Sonuç olarak, stres tolerans özelliği, deniz seviyesinden dağlık kesimlere kadar adapte olmuş birçok çeşidi ile farklı tarımsal çevre koşullarına uyum yeteneği, besin içeriği ve ekonomik değeri sayesinde quinoa bitkisi marjinal tarım alanları için alternatif bir ürün olarak önerilebilir.

Anahtar Kelimeler: Quinoa, kuraklık ve tuzluluk stresi, sulama suyu kalitesi, kısıntılı sulama

Introduction

Agricultural production is increasingly faced with environmental constraints. In particular, drought, salinity and desertification are among important environmental factors resulting in reduced agricultural productivity and limiting agricultural production areas and showing a widespread on a global scale.

Approximately one-third of the world land area is located in arid and semi-arid regions (Williams, 1999). In these regions, lack of rainfall, high evapotranspiration rate and mismanagement of limited water resources brings along drought, salinity and desertification problems. Salt affected area throughout the world is estimated at over 800 million hectares (Rengasamy, 2010). In Turkey, there is salinity problem in 1.5 million hectares of soils due to improper management of irrigation and inadequate drainage (FAO, 2014). As a result of unsustainable and faulty agricultural practices, a considerable amount of agricultural land is put out of production each year. Increased salinization of arable land is expected to cause a land loss of 50% in 2050 (Wang et al., 2003).

On the other hand, the negative impact on agricultural production of climate change, which creates significant changes in environmental conditions and adds new ones to these problems, is already beginning to be observed. The Mediterranean region, which Turkey is also found in, may be a vulnerable region to climate change (Giorgi and Lionello, 2008).

For sustainable agricultural production in the changing environmental conditions; the agricultural practices and cropping systems should be reorganized by considering these new circumstances. One of the approaches for this purpose is to investigate and include in the cropping system plant species which can tolerate abiotic stresses and adaptable to unfavorable conditions.

Quinoa (*Chenopodium quinoa* Willd.) is an annual grain plant originated from the Andean region of South America. This plant is known by resistance to various abiotic stresses such as salinity, drought and frost as well as high nutritional value. Quinoa has been cultivated in diverse environmental conditions include low precipitation, high evapotranspiration rate, frost and soil salinity for thousands years (Jacobsen, 2003). It has adapted to different agro-ecological zones range from sea level up to 4000 m altitude with its rich genetic diversity (Garcia et al., 2003; Jacobsen, 2003).

The United Nations Food and Agriculture Organization (FAO) declared 2013 as the "International Year of Quinoa" with the main objective to focus world attention on the role that quinoa's biodiversity and nutritional value play in food security (FAO, 2011). Quinoa has been indicated as a good candidate to offer food security, especially in the face of the predicted future world scenario of increasing salinization and aridity (Ruiz et al., 2014). In recent years, it has attracted interest all over the world and quinoa cultivation has begun expand in many countries in Europe, Africa and Asia (FAO, 2013).

In this study quinoa was introduced as a new crop for Turkey and cultivation possibilities of quinoa in arid and salt affected areas of the country was evaluated in the light of the research carried out in Cukurova University between the years of 2009 and 2012.

Quinoa Plant

Botanical Description

Quinoa is an annual herbaceous, dicotyledonous crop species belonging to the C3 group of plants (Jacobsen et al., 2003). It has been cultivated in the Andean region of Bolivia and Peru over a period of 5000 years (Jacobsen et al., 1994; Bhargava et al., 2006; Vega-Galvez et al., 2010). It is a member of the family Amaranthacease and referred as a pseudo-cereal plant.

Quinoa grows from 0.5 to 3 m in height, depending on environmental conditions and genotype (Oelke et al., 1992; FAO, 1994). The tap root system of plant is highly branched and this well-developed, deep root system makes plants more resistant to drought (Oelke et al., 1992; FAO, 1994; Bhargava et al., 2006). Quinoa has a branched or unbranched woody stem. The thickness of stem varies from 1 to 8 cm. Broad leaves are usually green in younger plants but they turn to yellow, red or purple as plant matures. There is a large panicle, 5-30 cm in diameter and 15-70 cm in height, on the top of the plant. The panicle consists in small flowers producing one seed per flower (Geerts et al., 2008a). Quinoa seed is cylindrical in shape with a diameter of 1.5 to 2.6 mm (FAO, 1994). Seed color varies from white, yellow, red to black depending on cultivars. The 1000 grain mass is generally low (3-6 gr) due to the small seeds (Geerts et al., 2008b).

Climate and Soil Requirements

Quinoa shows well development in medium-textured soils which have high organic matter with good drainage and moderate slopes. At the same time, quinoa is well adapted to grow under unfavorable soil and climatic conditions (Garcia et al., 2003). It has been cultivated on various types of soils including quite poor, saline or inadequately drained marginal soils with a wide pH range from 4.8 to 8.5 in Bolivian salt flats (Jacobsen et al., 1994; Bosque Sanchez et al., 2003).

Quinoa adapts to adverse climatic conditions. It can grow at relative humidity from 40% to 88% and temperatures between -4 °C and 38 °C (FAO, 2011). It is resistant to lack of the soil moisture. Even in the climatic condition that is the total annual precipitation is 100-200 mm, quinoa provides acceptable yields (Jacobsen et al., 2003; FAO, 2011).

The optimum soil temperature for germination of quinoa seeds is 8-10 °C and the optimum sowing depth is 1-2 cm (Jacobsen, 2003). It is important that a fine-structured, moist seed bed preparation because the small size of the seeds increase the germinate sensitivity. Quinoa responds well to nitrogen fertilizers. Nitrogen applications, rates up to 150 mg kg^{-1} soil, increase the grain yield of quinoa (Lavini et al., 2014).

The length of the growing season ranges from 90-180 days depending on cultivar and climatic conditions (Jacobsen, 2003).

Stress Tolerance of Quinoa

Quinoa has the ability to tolerate of various abiotic stresses such as drought, salinity, different soil pH, high solar radiation, cold, and night frost (González and Prado, 1992; Jensen et al., 2000; Geerts et al., 2008a).

Quinoa develops unique resistance mechanisms to water stress allowing this plant to adapt to harsh conditions in arid and semi-arid regions (Jensen et al. 2000; Jacobsen et al. 2003). The plant avoids the negative effects of drought through its deep ramified root system, special vesicular glands, small and thick-walled cells, reduction of leaf area and dynamic stomata behaviors (Jensen et al., 2000).

Quinoa is a salt-tolerant plant that survives even when irrigated with 100% sea water (Koyro and Eisa, 2008). The plant can accumulate salt ions in its tissues and adjust leaf water potential in order to maintain cell turgor and transpiration (Jacobsen 2003; Gómez-Pando et al., 2010). With significant varietal differences; under moderate saline conditions (10-20 dS m^{-1}) quinoa yield is higher than lower salinity in the root zone. Thus, this plant can be defined as a facultative halophyte rather than a glycophyte (Bosque Sanchez et al., 2003; Jacobsen et al., 2003).

Quinoa is also less affected frost than many other crops. It can withstand for up to 4 hours at -8 °C, depending on phonological stage and variety (Jacobsen et al., 2003).

Nutritional Value of Quinoa

Its high gluten free nutritional component is another characteristic of quinoa. It is the unique food crop that contains all the essential amino acids, trace elements and vitamins, and is also gluten-free (FAO, 2013).

The protein content of quinoa ranges between 13.8 and 21.9% (FAO, 2011). It has well-balanced amino acid composition when compared with reference patterns from the World Health Organization (Wright et al., 2002). It is also a rich source of dietary fiber and natural antioxidant such as vitamin E (Alvarez-Jubete et al., 2010, Vega-Galvez et al., 2010).

Quinoa seeds are being used as whole grain like rice or as flour by processing in many different ways. Quinoa flour is being used alone or by mixing flour of the other grains to make bread, pasta, cake, breakfast cereal and other pastries (FAO, 2011). Gluten free quinoa grains are suitable for preparation special diets for coeliac disease. Although there is no commercial value of quinoa leaves and green parts is a rich source of nutrients.

Despite of the high nutritional value, quinoa seeds also contain the anti-nutritious component saponin in the seed coat in a certain concentration, depending mainly on the variety (Ward, 2000). Saponin need to be removed from seed coat before consumption.

Quinoa Production and Market

Quinoa cultivation is spread across a broad area including parts of Bolivia, Peru, Ecuador, Colombia, Argentina and Chile (Fuentes et al., 2009). It has recently gained worldwide attention thanks to its nutritional value and remarkable adaptability to various environmental conditions (Jacobsen et al., 2003). Today quinoa cultivation has expanded from South America to many countries including USA, Canada, Denmark, France, Italy and Spain around the world (FAO, 2013).

Peru and Bolivia are main producer countries with approximately 90,000 tons of total quinoa production in 2012 (FAOSTAT, 2014). These two countries together supplies over 90% of demand in the world market. In terms of the amount of production, USA, Ecuador and Chile follow Peru and Bolivia, with pretty small scale production (FAO, 2013). In recent years, especially in USA and Europe demand for quinoa is increasing rapidly and the supply producing countries is insufficient to meet the demand (Jacobsen, 2003; Bhargava et al., 2007). Quinoa has a great potential for increased production in the Mediterranean region for consumption and supplying an increasing international market (Jacobsen et al., 2012).

Grain size, color and quality are factors that affect the market price of quinoa. The increase in demand over the last decade in the international market has led price of quinoa to increase exponentially. In 2012, export prices of quinoa were above USD 3,000 tons and tend to rise (FAO, 2013).

Quinoa in Turkey

Quinoa is a new crop in Turkey. Quinoa has been introduced for the first time within the 'Sustainable water use securing food production in dry areas of the Mediterranean region (SWUP-MED) Project' carried out between the years of 2009-2012. The development of climate-proof food crops that better utilize agricultural areas in Mediterranean countries affected by climate change has been supported by the SWUP-MED project.

A number of researches on quinoa were conducted in Cukurova University for four years within the project. The Danish-bred quinoa cultivar, Titicaca, was irrigated with fresh and saline water whose electrical conductivity (ECw) ranging from 0.26 to 40 dS m^{-1}. The growth, yields and responses to drought and salinity stresses of plant were investigated under conditions of full irrigation, deficit irrigation and partial rootzone drying (PRD) with fresh and saline water along with rainfed (non-irrigated) conditions.

Plant growth parameters such as plant height, leaf area index (LAI), dry matter and grain yield showed that Titicaca variety of quinoa is well adapted to the Mediterranean environmental conditions. This result is in agreement with the results of researches conducted in Italy, Morocco and Syria which are suggest that quinoa cv. Titicaca could be cultivated successfully in Mediterranean climatic conditions (Lavini et al., 2014).

The suitable sowing period of quinoa is March-April at low elevations and April-May at high altitudes in Turkey.

The grain yield of quinoa ranged between 2.0 and 3.0 t ha^{-1} under non-stressed conditions by years. In Denmark, Razzaghi et al. (2011a) obtained 3.3 t ha^{-1} yield from quinoa cv. Titicaca under non-stressed conditions while it was reported that total grain yield of same variety ranged from 1.9 to 3.3 t ha^{-1} in Italy (Lavini et al., 2014). In Bolivia 3.7 t ha^{-1} (Garcia et al., 2003); in Chile 2.6 t ha^{-1} (Martinez et al., 2009) and in Morocco 3.3 t ha^{-1} (Hirich et al., 2014) grain yields has been obtained from different quinoa varieties. Pulvento et al. (2010) reported that total grain yields changed depending on quinoa cultivars and planting time between 1.5 and 3.4 t ha^{-1}. According to these results, grain yields of quinoa under non-stressed conditions vary depending on plant cultivars, sowing date and environmental conditions such as soil and climate.

Irrigation of quinoa with saline water at ECw 5 dS m^{-1} salinity level did not cause yield loss or a decrease in plant growth, biomass and 1000 grain mass. In higher salt concentrations, in case the plant irrigated with water at EC_w 10, 20, 30 and 40 dS m^{-1} salinity level, yield reductions were emerged in comparison non-stressed conditions. Grain yields of full irrigated quinoa at different salinity level in the years 2010, 2011 and 2012 are shown in Figure 1. ECw 10 dS m^{-1} and higher irrigation water salinity caused yield losses at rates ranging from 2% to 27.5%. On the other hand, quinoa could cope with high salinity in the root zone up to 40 dS m^{-1} of electrical conductivity of irrigation water, which many other crops couldn't tolerate this salinity level. Similar results has been obtained in Denmark (Razzaghi et al., 2011b), Italy (Cocozza et al., 2012) and in Morocco (Lavini et al., 2014.

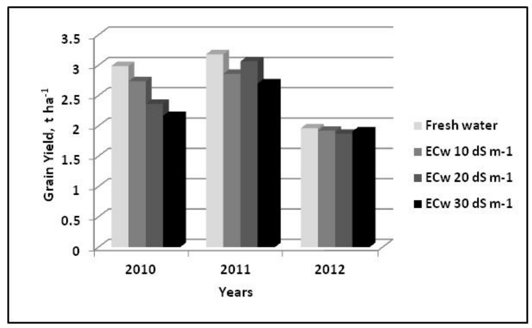

Figure 1. Grain yields of quinoa under different irrigation water salinity in 2010, 2011 and 2012.

Lack of the water in the root zone is another factor affecting quinoa grain yield. In the first research year, deficit irrigation or PRD treatments that supplied 50% less water did not affect quinoa yield. In the following years, important differences emerged between full irrigation and deficit irrigation in different proportions. Irrigation water limitation in the rate of 25%, 33%, 50%, 67% and 75% has led to yield losses about 14-40% in comparison with full irrigation. Moderate deficit irrigations (67% or 50%) resulted in significantly greater yield than severe deficit irrigations (33% or 25%). The combination of drought and salinity stress created more effects on quinoa yields in comparison with stand-alone drought or salinity. At the same salinity level, full irrigations resulted higher yields compared deficit irrigations. In all cases, water productivity (WP) of deficit irrigations was higher than its value under full irrigations. The yield losses were changed between 23% and 42% under the rainfed (non-irrigated) conditions. Razzaghi et al. (2012) referred that soil-drying during the grain filling stage significantly decreased the seed yields of quinoa Titicaca. Cocozza et al. (2012) suggested that a certain amount of water supplied during flowering and grain filling is enough to stabilize quinoa yield even for severe deficit irrigation. Deficit irrigation can stabilize yields at a level that is significantly higher than under rainfed cultivation (Geerts et al., 2009).

Conclusion

Quinoa is known as a stress tolerant plant and it is well adapted to different environmental conditions with its genetic diversity. As well as these features, high nutritional value of quinoa grains has made this plant an important crop for food security. In recent years quinoa has gained increasing interest on global scale and quinoa cultivation has begun expand many countries in Europe, Africa and Asia.

The research results of four years indicated that Titicaca variety of quinoa well adapted to the Mediterranean environmental conditions. Although high salinity caused an amount of yield reduction, quinoa could cope with salinity in the root zone up to 40 dS m^{-1} of electrical conductivity of irrigation water, which many other crops couldn't tolerate this salinity level. Quinoa has maintained its productivity even under rainfed conditions but moderate deficit irrigation show better results in terms of grain yield.

In conclusion, quinoa may be suggested as a new alternative crop especially for salt affected and dry agricultural areas of Turkey thanks to its stress tolerant characteristic, adaptability to different agro-environmental conditions with its various cultivars can grow from sea level to highlands, nutritional component and economic value.

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