American-Eurasian J. Agric. & Environ. Sci., 12 (10): 1350-1355, 2012
ISSN 1818-6769

DOI: 10.5829/idosi.aejaes.2012.12.10.1823

Quinoa- A Promising New Crop for the Arabian Peninsula

N.K. Rao and Mohammed Shahid

International Center for Biosaline Agriculture, P.O. Box 14660, Dubai, UAE

Abstract: Quinoa (*Chenopodium quinoa* Willd.) is a pseudocereal cultivated in the Andes region for thousands of years for its highly nutritive grain. It is known to grow well under extreme ecological conditions including drought and soil salinity, making it important for diversification of future agricultural systems. In a study conducted at Dubai based International Center for Biosaline Agriculture (ICBA), 20 accessions of quinoa were evaluated over two consecutive cropping seasons (winter 2007-08 and 2008-09) for their adaptation to the local climatic conditions. The five top-ranking accessions, selected on the basis of average yield obtained over the two seasons were further studied for their yield potential and other agronomic traits in a replicated field trial during the growing season, 2009-2010. There were significant differences among the accessions for plant height, number of primary branches and number of inflorescences per plant ($P<0.05$). However, differences among the accession for inflorescence length, grain yield per plant, fresh and dry biomass were found to be marginal ($P>0.05$). The grain yield, averaged over cultivars was found to be 456.6 g m^{-2} with Ames 13761 producing the maximum (533.6 g m^{-2}). The dry matter yield averaged 1,464 g m^{-2} over the accessions, the maximum being 1,624 g m^{-2} recorded in Ames 13742. Both the grain and dry matter yields obtained in the study were much higher than the average yields reported from the traditional growing areas in the Andes. The outstanding protein quality of the grain and its multiple uses as food for humans and feed for animals, its potential for the industry and more importantly, the unusually high tolerance of quinoa to salinity and drought, make quinoa an excellent choice for the diversification of future agricultural systems in the Arabian Peninsula and other regions with similar ecologically extreme conditions.

Key words: *Chenopodium quinoa* · Alternative crop · Arabian Peninsula · Salinity · Drought · Yield potential

INTRODUCTION

The Arabian Peninsula is one of the driest regions in the world with very low and unreliable rainfall. It is also one of the hottest regions in the world with day temperatures in summer often exceeding 50°C. The soils reflect the aridity of the climate, most of them being poorly developed and rich in lime, gypsum and other salts. Due to the hot climate, the percentage of organic substance in the soil is very low (less than 0.5%) to support proper plant growth. The high percentage of calcium carbonate leads to many other problems related to soil fertility such as fixation of phosphorous and certain micronutrients. As a result, only a limited number of crops can be successfully grown under these conditions.

In the Arabian Peninsula, most countries depend almost entirely on groundwater to irrigate crops. In many countries, large-scale extraction has depleted the groundwater reserves faster than the aquifer recharge that depends on the scanty rainfall. Making matters even more difficult, the salinity of the ground water has increased substantially in many areas due to seawater intrusion. The growing urban areas are also taking priority over the scarce freshwater, leaving agriculture to use low-quality brackish and salty water that can increase the risk of soil salinization with adverse affects on agricultural productivity as most of the commonly cultivated crops, except date palm are not highly salt-tolerant. In this scenario, diversification of agricultural production systems through identification and introduction of new crops with tolerance to high levels of soil and water salinity and heat stress becomes crucial to sustain agricultural productivity. The genetic resources program of the Dubai-based International Center for Biosaline Agriculture (ICBA) has been studying a wide range of salt- and drought-tolerant crops new to Arabian Peninsula for their ability to grow and produce economic

Corresponding Author: N.K. Rao, International Center for Biosaline Agriculture, P.O. Box 14660, Dubai, UAE

Fig. 1: Quinoa growing at an experimental farm in Dubai. A. Flowering stage, B. Mature seed heads, C. Seed.

yields with the aim to introduce them to the farmers in the region. Among the few crops that performed well, quinoa (*Chenopodium quinoa* Willd.) appears to have significant potential for introduction to diversify the future agricultural systems in the region [1] (Fig. 1A-C).

Quinoa is a pseudocereal, considered to have originated in the Inca and Tiahuanaco regions of the Andes. For thousands of years it was the main food of the ancient cultures of the Andes. Quinoa seeds are generally used to make flour, soup and as breakfast cereal. Quinoa flour works well as a starch extender when combined with wheat flour or grain, or corn meal in making biscuits, bread and processed food. The seeds are also used for brewing beer and for animal feed. In poultry-feeding trials, chicks fed with a ration containing cooked quinoa made equal gains to those receiving maize and skimmed milk. Quinoa leaves can be eaten as a leafy vegetable, just like spinach. Quinoa seed coats usually contain bitter tasting compounds, mainly the saponins, which can be easily removed by washing in cold water or dehulling [2, 3]. Saponins have immense industrial importance and are used in soap, detergent, cosmetic and pharmaceutical industries [4].

The unique benefits of the cultivation of quinoa are due to its high nutritional value and its ability to thrive in extreme soil and climatic conditions. The protein content of quinoa ranges between 11 and 19% and is of very high quality, containing all eight amino acids essential for human health [3]. The balance of essential amino acids in quinoa is superior to wheat, barley and soybeans and compare well with the protein in milk. The exceptionally high levels of amino acids in quinoa provide valuable therapeutic properties such as: enhancing the immune function by aiding in the formation of antibodies, assisting in cell repair, calcium absorption and transport, involvement in the metabolism of fatty acids, and even preventing cancer metastasis. Quinoa is also a good source of dietary fiber and phosphorus and is high in magnesium and iron. Because of its high nutritional value and medicinal use, quinoa is recognized as a pseudocereal with the broadest and most complete nutritional composition known today [5, 6]. The Food and Agriculture Organization of the United Nations (FAO) has considered quinoa to be the "grain of the future". Taking into account the exceptional nutritional qualities, its adaptability to various growing conditions and potentially significant contribution to the fight against hunger and malnutrition, the thirty-seventh session of the General Conference of FAO adopted a resolution recommending the declaration of 2013 as the International Year of Quinoa [7].

In this paper, we present the results of preliminary evaluation on the growth performance and yield of quinoa from field trials conducted in Dubai and discuss its adaptation potential to the extreme growing conditions of the Arabian Peninsula for possible introduction as a salt-tolerant alternative crop to improve farm productivity and sustainability.

MATERIALS AND METHODS

Twenty germplasm accessions acquired from the United States Department of Agriculture (USDA) were evaluated for growth performance and yield at International Center for Biosaline Agriculture (ICBA) Research Station (25°05'49" N and 55°23'25"E) for two consecutive cropping seasons (Nov-Mar) in 2007-08 and 2008-09. The seeds were sown in the first week of November and each accession was planted in three 3 m-rows with spacing of 50 cm between the rows and one meter between two accessions. The distance between plants within each row was maintained at 25 cm. The plants were irrigated with low-salinity water (EC_w 2.8 dS cm^{-1}) using the drip system. Water was applied once every day for 20 min at a flow rate of 4 l h^{-1} per plant. The soil at the experimental site was fine sand and moderately alkaline (pH 8.2) with very low organic matter (<0.5%). Before sowing, the fertility of the soil was improved by incorporating organic fertilizer at the rate of 40 t ha^{-1} and during crop growth two split doses of NPK (20:20:20) at the rate of 50 kg ha^{-1} were applied by banding alongside the rows. The seeds were harvested at maturity when the plants have turned pale yellow and the lower leaves dropped. The best five accessions, selected on the basis of averaged grain yield over the two years were further evaluated under field conditions using a randomized block design (RBD) with three replications during winter 2009-10. Each accession was sown in a plot consisting of four rows of 3 m length. The agronomic practices adopted for crop growth were the same as those described above. Grain yield and other agronomic data such as days to flowering, number of primary branches, number of inflorescence, inflorescence length and biomass (fresh and dry matter yields) were recorded from five plants, randomly selected from the middle rows in each plot. The data on inflorescence length were based on five inflorescences, randomly selected from the five plants used for agronomic observations. Dry matter yield was determined by drying the samples initially under the sun for two days and then in a forced-drought oven (Memmert, model ULP 800) at 80°C for 48 hr. The data were subjected to analysis of variance (ANOVA) using the statistical software GenStat (Version 7.22 DE).

RESULTS AND DISCUSSION

The meteorological data from the weather station close to the experimental site showed that the average monthly maximum and minimum temperatures during the cropping seasons ranged from 23 to 33°C and from

Table 1: Grain yields in 20 quinoa accessions grown in winter 2007-08 and 2008-09.

		Yield (g m^{-2})		
Accession no.	Origin*	2007-08	2008-09	Mean
Ames 13220	Bolivia	84.57	100.95	92.76
Ames 13719	USA	74.61	87.05	80.83
Ames 13723	USA	80.09	134.42	107.25
Ames 13724	USA	132.32	62.42	97.37
Ames 13727	USA	111.39	133.02	122.2
Ames 13736	USA	57.50	109.07	83.29
Ames 13742	USA	359.86	118.12	238.99
Ames 13749	USA	211.06	79.25	145.16
Ames 13757	USA	187.26	120.32	153.79
Ames 13758	USA	64.81	3.32	34.06
Ames 13761	USA	60.50	258.42	159.46
Ames 21931	Bolivia	84.19	39.88	62.04
Ames 22154	Chile	50.85	45.13	47.99
Ames 22155	Chile	147.34	91.43	119.39
Ames 22157	Chile	118.58	133.33	125.95
NSL 106395	USA	105.77	119.25	112.51
NSL 106398	USA	54.00	193.92	123.96
NSL 106399	USA	167.10	148.65	157.87
NSL 86649	USA	53.86	143.1	98.48
PI 478410	Bolivia	58.06	13.27	35.67
Mean		113.19	106.72	109.95
SE		17.79	14.40	16.12

*USA might be the source but not the country of origin

Table 2: Growth, seed and biomass yields of five quinoa accessions grown in Dubai during winter (Nov-Mar) 2009-10.

Accession	Plant height (cm)	Number of primary branches	Days to flowering	Days to maturity	Number of inflorescences per plant	Inflorescence length (cm)	Seed yield ($g\ m^{-2}$)	Fresh biomass ($g\ m^{-2}$)	Dry biomass ($g\ m^{-2}$)
Ames 13742	112.6	38.7	67	122	28.9	21.9	453.6	4048	1624
Ames 13749	88.8	25.1	53	108	20.0	31.7	455.2	3120	1264
Ames 13757	113.2	32.9	55	99	27.2	24.3	374.4	3560	1496
Ames 13761	113.1	30.5	54	93	24.9	22.8	533.6	3120	1304
NSL 106399	86.5	30.6	60	104	25.1	21.1	461.6	3240	1608
Mean	*102.8*	*31.6*	*58*	*105*	*25.2*	*24.3*	*456.6*	*3416*	*1464*
LSD (P=0.05)	*23.9*	*8.5*	-	-	*4.6*	*NS*	*NS*	*NS*	*NS*

14 to 23°C, respectively. The data on grain yield of the 20 accessions from the two cropping seasons (2007-08 and 2008-09) are presented in Table 1. The grain and biomass yields of individual accessions, estimated from average single plant yields are expressed in $g\ m^{-2}$. The grain yield among accessions varied between 53.86 and 359.86 $g\ m^{-2}$ in 2007-08, and between 3.32 and 258.42 $g\ m^{-2}$ in 2008-09. Averaged over the two seasons, the yield ranged between 34.06 $g\ m^{-2}$ and 238.99 $g\ m^{-2}$ among the accessions. The mean yields was highest (238.99 $g\ m^{-2}$) in Ames 13742, followed by Ames 13761 (159. 5 $g\ m^{-2}$), NSL 106399 (157.87 $g\ m^{-2}$), Ames 13757 (153.79 $g\ m^{-2}$) and Ames 13749 (145.16 $g\ m^{-2}$). The data obtained from further evaluation of the five top-yielding accessions in 2009-10 are presented in Table 2. While the time to flowering among accessions ranged between 53 to 67 days, days to maturity varied from 93 to 122 days. Analysis of variance revealed significant differences for plant height, number of primary branches and number of inflorescences per plant ($P<0.05$). However, differences among accessions for all other traits including inflorescence length, seed yield per plant, fresh and dry biomass were found to be marginal ($P>0.05$). The seed yield among the five accessions ranged between 374.4 $g\ m^{-2}$ (Ames 13757) and 533.6 g per plant (Ames 13761) with an average of 456.6 $g\ m^{-2}$ over accessions. The dry matter yield, averaged over the accessions was 1,464 $g\ m^{-2}$, with accession Ames 13742 producing the maximum yield of 1,624 $g\ m^{-2}$. The similarity in seed and forage yields of the five accessions was probably because they had been pre-selected for their superior performance.

Under traditional rain-fed farming conditions, quinoa yields were reported to vary between 0.4-1.2 $t\ ha^{-1}$ and with improved management, yields exceeding 2 $t\ ha^{-1}$ were obtained [2, 8]. However, with supplemental irrigation and the addition of organic matter, grain yields ranging between 4.0 to 7.7 $t\ ha^{-1}$ were obtained in Chile [9]. In the current studies with the plant density of 8 plants m^{-2}, extrapolated mean yield of the five accessions was found to be 4.6 $t\ ha^{-1}$, which is within the range of high yields reported from Chile [9]. It should be noted that higher yields were obtained despite the use of a lower plant density than the optimal population of 32 plants per m^{-2} suggested for quinoa [2]. This is in line with the observation that higher densities do not necessarily present an advantage in terms of growth and yield because of quinoa's extraordinary capacity to compensate for missing plants by increased vigor and branching [10]. The experimental plots in this study were irrigated with low-salinity water (2.8 $dS\ m^{-1}$) and yield potential at higher levels of water and soil salinity was not investigated. However, studies at the International Potato Center (CIP) in Peru, showed that salt tolerance of quinoa is very high, indeed it is able to grow and produce in salt concentrations close to sea water [11, 12]. The studies at CIP also demonstrated that quinoa can be grown under extremely dry conditions with as little as 200 mm rainfall and in pure sand [5]. Recently, an evaluation of grain yields from two sites with distinct microclimates showed that quinoa can be cultivated with extremely low irrigation [9]. The yields over two seasons from low irrigation treatments (40-75 mm) ranged from 1.3 to 4.0 $t\ ha^{-1}$, compared to the yields of 4.8 to 7.7 $t\ ha^{-1}$ obtained under high irrigation treatments (150-250 mm). Quinoa has also been found to have potential for crop diversification in the desert area of Egypt [13]. Thus, in an experiment conducted in the sandy soils of South Sinai desert with 125 mm rainfall, the grain yield of 13 varieties with two supplementary irrigations ranged between 1.2 and 1.9 $t\ ha^{-1}$ demonstrating the value of quinoa as a new crop for arid climates.

The ability of quinoa to withstand high salinity and its alternative use as a forage crop also makes it valuable for forage production systems marginalized by increased soil and water salinity. In quinoa, dry matter yields of up to 8.8 $t\ ha^{-1}$ have been reported, with the vegetative parts harvested at flowering containing up to

22% crude protein, 52% carbohydrate and 1.5% ash [14, 15]. The average dry matter yield of 1,464 g m^{-2} (i.e. 14.6 t ha^{-1}) obtained in our study is significantly higher than that reported earlier, which suggest that quinoa has good potential also as an alternative forage for the salt-affected areas of the Arabian Peninsula.

The results from current study, in addition to showing that quinoa has good adaptation and can be successfully cultivated in the Arabian Peninsula, demonstrate the importance of cultivar selection for successful introduction. It is pertinent to add that genetic variability of quinoa is also very high, with cultivars adapted to grow from sea level to 4,000 m above sea level, from 40°S to 2°N latitude, and from cold highland climates to arid and hot desert conditions [5, 13], making it possible to select, adapt, and breed cultivars for a wide range of environmental conditions.

CONCLUSIONS

Based on the results from field trails under Dubai conditions and the earlier reports of tolerance to high salinity and drought, it can be concluded that quinoa can perform well under the ecologically extreme desert conditions. Therefore, quinoa holds great promise as a food, feed and forage crop for diversification of the agricultural production systems in salt-affected areas within the Arabian Peninsula as well as other regions with similar climatic conditions. However, it should be noted that the agronomic performances shown by the genotypes in present study are indicative of the potential for crop improvement and further investigations are needed to study the yield potential of a much wider range of genetically diverse accessions at various soil and water salinities. Quinoa is a predominantly self-pollinating species and considerable variation exists between cultivars for many of the desired characters. Therefore, it should be possible to select better adapted genotypes with high yields and nutritional quality combined with salt-and drought-tolerance. Identification of desirable genotypes needs to be followed by work on optimization of cultural practices to maximize productivity under the local conditions. The introduction and scaling-up of novel crops in non-traditional environments also requires the study of the entire chain, from planting to product – including the basics of production and harvesting, storage and processing technologies, product development, evaluation, marketing studies and economics.

REFERENCES

1. Rao, N.K., M. Shahid and S.A. Shahid, 2009. Alternative crops for diversifying production systems in the Arabian peninsula. Arab Gulf Journal of Scientific Research, 27: 195-203.
2. Oelke, E.A., D.H. Putnam, T.M. Teynor and E.S. Oplinger, 1992. Quinoa. In Alternative Field Crops Manual, University of Wisconsin-Extension, Cooperative Extension and University of Minnesota: Center for Alternative Plant and Animal Products and the Minnesota Extension Service (Available at: http://www.hort.purdue.edu/newcrop/afcm/quinoa.html).
3. Bhargava, A., S. Shukla and D. Ohri, 2006. *Chenopodium quinoa* – An Indian perspective. Industrial Crops and Products, 23: 73-87.
4. Johnson, D.L. and S.M. Ward, 1993. Quinoa. In: New Crops, Eds., J. Janick and J.E. Simon. Wiley, New York, pp: 222-227.
5. Jacobsen, S.E., A. Mujica and C.R. Jensen, 2003. The resistance of quinoa (*Chenopodium quinoa* Willd.) to adverse abiotic factors. Food Reviews International, 19: 167-177.
6. Vega-Galvez, A., M. Miranda, J. Vergara, E. Uribe, L. Puente and E.A. Martinez, 2010. Nutrition facts and functional potential of quinoa (*Chenopodium quinoa* Willd.), an ancient Andean grain: a review. Journal of the Science of Food and Agriculture, 90: 2541-7.
7. FAO, 2011. Report of the Conference of FAO. Thirty-seventh Session, Rome, 25 June □ 2 July 2011. FAO, Rome.
8. Schlick, G. and D.L. Bubenheim. 1996. Quinoa: Candidate crop for NASA's Controlled Ecological Life Support Systems. In Progress in New Crops, Ed., J. Janick. ASHS Press, Arlington, pp: 632-640.
9. Martinez, E.A., E. Veas, C. Jorquera, S.R. Martin and P. Jara, 2009. Re-introduction of quinoa into arid Chile: cultivation of two lowland races under extremely low irrigation. Journal of Agronomy and Crop Science, 195: 1-10.
10. Spehar, C.R. and J.E.S. Rocha, 2009. Effect of sowing density on plant growth and development of quinoa, genotype 4.5 in the Brazilian Savannah highlands. Bioscience Journal, 25: 53-58.

11. Jacobsen, S.E., H. Quispe and A. Mujica, 2001. Quinoa: An alternative crop for saline soils in the Andes. In Andean roots and tubers and other crops. CIP Program Report 1999-2000. International Potato Center, Lima, Peru, pp: 403-408.
12. Koyro, H.W., H. Lieth and S.S. Eisa, 2008. Salt tolerance of *Chenopodium quinoa* Willd. In Mangroves and Halophytes: Restoration and Utilization, Eds., Leith H., M.G. Surce and B. Herzog. Springer, Dordrecht, the Netherlands, pp: 133-145.
13. Shams, A., 2011. Combat degradation in rain-fed areas by introducing new drought tolerant crops in Egypt. International Journal of Water Resources and Arid Environments, 1: 318-325.
14. Sells, J.E., 1989. Combinable alternative crops. AFRC Institute of Engineering Research, Bedford, UK.
15. Stølen, O. and G. Hansen, 1993. Introduction of New Crops in Denmark. In New Crops for Temperate Regions, Eds., K.R.M. Anthony, J. Meadley, and G. Robbelen. Chapman and Hall, London, pp: 45-53.