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An Assessment of Quinoa (*Chenopodium quinoa* Willd.) Potential as a Grain Crop on Marginal Lands in Pakistan

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Abstract: Quinoa belongs to family *Chenopodiaceae* and is related to well-known agricultural crops such as sugar beet (*Beta vulgaris*), spinach (*Spinacia oleracea*) and amaranth and is known to be an integral food grain source in the Andean region, from where it spread to other regions and continents. It is known for its frost, drought and salt tolerant characteristics. It is an annual plant with tap root system and fruit is a small seed called achene. Quinoa leaves contain a sufficient amount of ash (3.3%), fiber (1.9%), nitrates (0.4%), vitamin E (2.9 mg /100 g) and Na (289 mg/100 g). Quinoa flour contains 11.2% moisture, 13.5% crude protein, 6.3% ether extract, 9.5% crude fiber, 1.2% total ash and 58.3% carbohydrate. The seed proteins are rich in amino acids like lysine, threonine and methionine that are deficient in cereals. It is cooked as rice and is used to make bread, soups, biscuits and drinks. It has potential to be grown as food, feed or as a oil seed crop.

Key words: Achene yield · Drought resistant · Food and feed · Salt tolerance · Saponins

INTRODUCTION

Food security exists when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life as defined by World food summit of 1996. It includes both physical and economic access to food that meets people's dietary needs as well as their food preferences. Food security is built on three pillars such as food availability (sufficient quantities of food available on a consistent basis), food access (having sufficient resources to obtain appropriate foods for a nutritious diet) and food use (appropriate use based on knowledge of basic nutrition and care) [1]. But more than 60% population of Pakistan is food insecure and 50% women and children are malnourished. 35% of child deaths (under age 5) in the country are linked to malnutrition despite the fact that agriculture continues to remain backbone of Pakistan's economy. Furthermore, the skyrocketing population and water shortages for agricultural use have forced the researchers to focus energies to bring marginal lands under plough to increase the food supplies. The concept of marginal lands is often interchangeably used with other terms such as unproductive lands, waste lands, under-utilized lands, idle lands, abandoned lands, or degraded lands [2-4]. Strijker [5] and Schroers [6] defined marginal land as an area where a cost-effective production is not possible, under given site conditions, cultivation techniques and agricultural policies. These marginal lands are not suitable for all types of crops and only crops with characteristics to sustain biotic as well as abiotic stresses can be grown on marginal lands. Quinoa (*Chenopodium quinoa* Willd.) is one of such crops that can be grown on marginal lands in Pakistan. Quinoa belongs to genus *Chenopodium* and family *Chenopodiaceae*. This genus consists of about 250 species [7] including various herbaceous, suffrutescent and arborescent perennials, although most species are colonizing annuals [8]. *Chenopodium* species have been cultivated for centuries as a leafy vegetable (*Chenopodium album*) as well as an important subsidiary grain crop (*Chenopodium quinoa* and *C. album*) for human and animal foodstuff, due to high-protein and a balanced amino-acid spectrum with high lysine (5.1–6.4%) and metionine (0.4–1.0%) contents [9-11]. Quinoa belongs to the group of crops known as pseudo-cereals [12-15] and is related to well-known agricultural crops such as sugar beet (*Beta vulgaris*), spinach (*Spinacia oleracea*) and amaranth. In the past few decades, interest in quinoa (*Chenopodium quinoa* Willd.) outside of South America has greatly increased. Quinoa is considered as a

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multipurpose agricultural crop because its seeds may be utilized for human food, in flour products and in animal feedstock because of its high nutritive value [16]. But due to its significant ability to adapt to a wide range of agro-ecological conditions, nutritional richness and its high level of hardiness in marginal environments, the crop has earned special attention from agronomists and nutritionists alike.

The present study explores the potential of quinoa as a grain crop to be grown on the marginal lands of Pakistan by bringing into light the ability of quinoa to withstand various abiotic stresses such as frost, drought and salt stress, in order to ensure food security of teeming millions and to alleviate malnutrition in the country, particularly in the wake of emerging water crisis and skyrocketing population.

Quinoa in Andean Region and Other Varying Environments: Quinoa is known to be an integral food grain source in the Andean region since 3000 B.C. [17] and occupies a place of prominence next only to maize [18]. However, this region was conquered by the Spaniards in 1532 A.D. and crops such as potato and barley were introduced on large scale which put quinoa to the background. However, the sporadic failure of green revolution in the Andes and enormous destruction of other crops by droughts, once again brought native crops, like quinoa, to the forefront as it showed much less reduction in the yields even after confronting severe conditions [12], such as drought, frost, soil salinity, hail, snow, wind, flooding and heat. Quinoa has been tested in diverse climatic regions of USA, Canada, India, England, Denmark, Greece, Italy and other European countries [19-25]. Now, it has been successfully grown in Chile, Ecuador, Peru and northern Argentina [8]. Recently it has been introduced in some European, Asian and some African countries as a forage and grain crop [26, 27].

Botany of Quinoa: Quinoa is an annual plant having an erect stem with alternate leaves. It can attain a height up to 1.5m, with large number of branches and a big leaf size. It develops a highly specialized tap-root system [28], which can penetrate as deep as 1.5m below the surface and serves as a safety valve against drought. The inflorescence is a panicle which is usually 15–70 cm in length. An important feature of quinoa is the presence of hermaphrodite and unisexual female flowers [29-31]. It consists of small flowers, each of which produces one seed of about 2.5 mg and a diameter of 1 mm. The fruit is an achene, comprising several layers [32-36], from outwards to inside and may be conical, cylindrical or ellipsoidal, with saponins concentrated in the pericarp. Seed size and color are variable [26], where black is dominant over red and yellow, which in turn are dominant to white seed color.

Agronomy of Quinoa: Quinoa can be grown on a variety of soils including marginal soils with a wide pH range from 4.5 to 9.5 [18, 19]. Seeds should be sown 1–2 cm deep in a fine structured, moist seedbed [22]. Berti *et al*. [37] suggested that quinoa responded strongly to nitrogen fertilization and grain yield did not show decrease with increasing N rates. Nitrogen application is known to increase seed yield as well as the protein content of the seeds [38]. Heavy doses of phosphorus and potash are known to increase vegetative growth without any increase in seed yield [39]. Quinoa is a drought-tolerant crop having low water requirement, though yield is significantly affected by irrigation [40, 41]. Quinoa is infected by a variety of pathogens, which cause several diseases like mildews, damping off, blight, mosaic, etc., but downy mildew is the most severe pathogen on quinoa and is known to cause yield reduction of 33–58%, even in the most resistant cultivars [42-45]. The maximum yields of 1439 kg/ha on sandy loam soils were obtained with 208mm of water (rainfall and irrigation) [46], but it cannot be called conclusive since the study was limited to a single location and soil type. Seeds can be threshed by traditional methods like sticks or animals, as well as by threshers. A fanning mill and gravity separator is necessary to remove trash from the seed after combining. Grains should be totally dry before storage.

Nutritional Value of Quinoa and Uses: It is sold either as whole grain that is cooked as rice or in combination with other dishes. It can be fermented to make beer, or used to feed livestock [47-49]. Whole plant is being used as green forage to feed cattle, pigs and poultry in many Latin American countries. Quinoa is being consumed in bread, soups, biscuits, drinks, etc. It has a high protein content, but what is more important is a high protein quality with a high level of the essential amino acids and a wide range of vitamins (A, B2, E) and minerals (Ca, Fe, Cu, Mg, Zn) [16]. Quinoa leaves contain a sufficient amount of ash (3.3%), fiber (1.9%), nitrates (0.4%), vitamin E (2.9 mg /100 g) and Na (289 mg/100 g) [13]. Prakash *et al.* [9] reported that leaves contain about 82–190 mg/kg of carotenoids, 1.2–2.3 mg/kg of vitamin C and 27–30 mg/kg of protein. Quinoa is referred to as pseudo-oilseed crop (Cusack, 1984), because an exceptional balance between oil, protein

Table 1: Mineral content of quinoa grain (ppm) as compared to other cereals (Johnson and Ward, 1993)

Crop	Ca	P	Fe	K	Na	Zn
Wheat	550	4700	50	8700	115	14
Barley	880	4200	50	5600	200	15
Quinoa	1274	3869	20	6967	115	48

and fats exists in its seeds. High nutritional value of quinoa seeds is mainly attributed to the high protein content (14%) and wide range of minerals and vitamins [16], while starch accounts for 52-60% of grain weight and fat concentrations up to 9.5%, so can be a potentially valuable new oil crop. On the basis of 1 kg dry weight, quinoa has more Ca (1487 mg), Fe (132 mg), K (9267 mg), Mg (2496 mg), Cu (51 mg), Mn (100 mg) and Cl (1533 mg) than other cereals, mineral content of quinoa in comparison with wheat and barley are given in Table 1. Quinoa flour contained 11.2% moisture, 13.5% crude protein, 6.3% ether extract, 9.5% crude fiber, 1.2% total ash and 58.3% carbohydrate [14]. The seed proteins are rich in amino acids like lysine, threonine and methionine that are deficient in cereals. The seed is used to make different food products including breads, biscuits, cookies, crepes, muffins, pancakes and tortillas in Americas. More recently, attention has been given to quinoa for people with celiac disease (allergy to gluten), as an alternative to the cereals wheat, rye and barley, which all contain gluten [22]. Protein quality, starch properties and other nutrients of the quinoa seeds have been studied, but other aspects related to the technological applications have received less attention. Because of its low baking quality, which is due to the absence of gluten, quinoa flour can only partially substitute wheat flour in bread making and other baked products. In Denmark, bread for celiac people consisting of only quinoa as starch source is produced. A crunchy texture, a unique shape and a nutty or wheat-like flavor in baking products are described by Linnemann and Dijkstra, [50]. Bread making ability of wheat flour mixed with quinoa seeds has not been studied yet. For the bread making process, 10% substitution of wheat flour with quinoa flour has been reported to be acceptable based on dough stability, loaf volume, weight, structure, texture, taste and color [51, 52]. The possibility of using quinoa flour inclusion in baked products up to 20–30% was mentioned. However, a bitter aftertaste at such high quinoa flour levels was reported. This is probably due to a deficient seed processing, leaving some of the hull. Good baking and sensory properties were obtained for mixtures with up to 10% of quinoa flour. So far, the technology for incorporation of quinoa seeds into baking products has not been developed. Despite of the high nutritional value of the seeds, they also contain the anti-nutritious component saponin in a certain concentration, depending mainly on the variety. Saponins need to be removed before consumption and are now sometimes mentioned to be useful for industrial purposes. They are removed either by the wet method, i.e. washing and rubbing in cold water, or by dry method, i.e. toasting and subsequent rubbing of the grains to remove the outer layers [53-56]. On commercial scale, saponins are removed by abrasive dehulling [57], but in this method, some saponin remains attached to the perisperm ([58]. Saponin removal by dry method reduces the vitamin and mineral content to some extent the loss being significant in case of potassium, iron and manganese [59-63]. Saponins have immense industrial importance and are used in the preparation of soaps, detergents, shampoos, beer, fire extinguishers and photography, cosmetic and pharmaceutical industries [38].

Potential of Quinoa to Tolerate Abiotic Stresses: Quinoa exhibits high level of resistance to several predominant adverse factors, like soil salinity, drought, frost, diseases and pests [22]. It can tolerate soil pH from 4.8 to 9.5 because of mycorrhizal associations, thus maximizing the use of scarce nutrients [17].

Frost Stress: Quinoa resists frost before the flower-bud formation stage [64]. Quinoa has been shown to possess a super-cooling capacity of 5°C, a mechanism that prevents immediate damage by low temperatures. However, the main mechanism for the frost resistance of quinoa seems to be that it tolerates ice formation in the cell walls and the subsequent dehydration of the cells, without suffering irreversible damages. A high content of soluble sugars implies a high level of frost tolerance and causes a reduction in the freezing temperature and the mean lethal temperature

Drought Stress: About one third of the world's land surface is characterized as arid or semiarid, which makes drought one of the main constraints to agriculture worldwide [65]. The severity of the problem is increasing due to global warming. This has already led to serious droughts of unusually long duration in northern Kenya, Ethiopia, Afghanistan and parts of Pakistan and India [66]. 16% of cultivated area of Pakistan is rainfed as there are no ensured sources of irrigation and crops are entirely depended upon rainfall for their water requirement. Another factor contributing to drought is population growth, as 190 million population need water for daily consumption and matter of fact is per capita water availability in Pakistan has decreased for 5600 to 1066 m^3 $person^{-1}$ $year^{-1}$. These climatic and demographic factors are increasing the pressure on agricultural land to yield more food. This situation reveals the crucial need to use all available resources to improve knowledge of drought-resistance mechanisms in cultivated plant species. However, the unpredictability of drought occurrence and its severity, timing, duration and interaction with other abiotic and biotic stresses, complicate these endeavors.

The drought resistance of quinoa is attributed to morphological characters, such as an extensively ramified root system and presence of vesicles containing calcium oxalate that are hygroscopic in nature and reduce transpiration [67]. Physiological characters indicating drought resistance is low osmotic potential, low turgid weight/dry weight ratio, low elasticity and an ability to maintain positive turgor even at low leaf water potentials [68, 69]. Vacher [70] analyzed the responses of quinoa to drought and found that stomata conductance remained relatively stable with low but ongoing gas exchange under very dry conditions and low leaf-water potentials. Quinoa maintained high leaf-water use efficiency to compensate for the decrease in stomata conductance and thus, optimized carbon gain with a minimization of water losses. Jensen *et al.* [71] studied the effects of soil drying on leaf-water relations and gas exchange in *C. quinoa*. High net photosynthesis and specific leaf-area values during early vegetative growth probably resulted in early vigor of the plant supporting early water uptake and thus, tolerance to a following drought. The leaf water relations were characterized by low osmotic potentials and low turgid weight/dry weight (TW/DW) ratios during later growth stages sustaining a potential gradient for water uptake and turgor maintenance under high evaporation demands. Garcia *et al.* [72] and Gee *et al.* [73] calculated the seasonal yield response factor (Ky) for quinoa that was lower to that of groundnut and cotton. This low Ky value for quinoa indicated that a minor drought stress does not result in large yield decrease. Several mechanisms related to drought resistance seem to be present in quinoa, including drought escape, tolerance and avoidance, with significant varietal differences. Drought escape occurs primarily due to early maturity and is, therefore, an important characteristic in areas with risk of drought in either the beginning or end of the growth season. Quinoa tolerates drought through growth plasticity, tissue elasticity and low osmotic potential. The plant also avoids the negative effects of drought through its deep, dense root system, reduction of leaf area, through leaf dropping, special vesicular glands, small and thick-walled cells, adapted to large losses of water without loss of turgor and stomata behavior.

Salt Stress: Soil salinization must be regarded as one of the major problems in agriculture. These soils are primarily found in arid regions, where drought, extreme temperatures and nutrient deficiency go hand in hand and where scarce precipitation and high evaporation hinder a washing out of the salts. Hence, salts accumulate in the upper layers of the soil. It is estimated that between 3.4 and 9.5×10^6 km^2, equivalent to ca. 20% of the arid and semiarid soils of the world, or 6% of the world area, are regarded as saline [65]. If the increase in salinization due to irrigation is considered, estimated to be 50% of the irrigated land, the size of the problem is obvious.

It accumulates salt ions in tissues, which adjusts leaf water potential, enabling the plant to maintain cell turgor and limit transpiration under saline conditions [23]. In addition, significant increase in leaf area at salinity level of 11 dSm^{-1} as compared to 3 dSm^{-1} has been noted [74-77]. Bhargava *et al.* [78-81] obtained marginal decrease in grain yield of quinoa on sodic soil (pH 8.5–9.0) in comparison to normal soil. Quinoa has demonstrated the ability to accumulate salt ions in its tissues in order to control and adjust leaf water potential. This enables the plants to maintain cell turgor and limit transpiration under saline conditions, avoiding physiological damage from drought and thus potential death.

Quinoa Future in Pakistan: There is no crop other than quinoa that resists the combination of adverse factors from frost to drought and from salinity to water logging. The genetic variability of quinoa is huge, with cultivars of quinoa being adapted to growth from sea level to 4000 meters above sea level, from 40°S to 2°N latitude and from cold, highland climate to subtropical conditions. This makes it possible to select, adapt and breed cultivars for a wide range of environmental conditions that persist in Pakistan, particularly in arid areas of pothowar region. The low water requirement shows its drought-hardy nature and makes it suitable for cultivation on large tracts of Pakistan where assured irrigation is non-existent and farmers have to depend on seasonal rains.

Quinoa is considered a multipurpose agro-industrial crop having multipurpose benefit for Pakistan. The seed may be utilized for human food and in flour products and in animal feed stocks because of its high nutritive value. So its seed must be imported and various genotypes must be seggeragated for their suitability in Pakistani conditions. The specific advantageous properties of quinoa for industrial uses must be identified and exploited and process technologies enabling exploitation of such properties must be developed. To be successful these products must compete with other raw materials that are often cheap, readily available and of acceptable quality. Quinoa starch with its uniformly small granules has several potential industrial applications. Possible industrial products suggested from quinoa are flow improvers to incorporate into starch flour products, fillers in the plastic industry, anti-offset and dusting powders and complimentary protein for improving amino acid balance of human and animal foods. Saponins may be interesting as potential insecticides, antibiotics and fungicides and to the pharmaceutical industry as a mediator of intestinal permeability, which could aid the absorption of specific drugs and for reducing the level of cholesterol, particularly for heart patient. So quinoa holds interest as a future grain crop as food, feed or oil seed crop having highest nutrient value to offer to undernourished Pakistanis.

Production Technology Development and Genetic Program: The need of hour is to develop a comprehensive agronomic program to develop production technology of quinoa according to different climatic regions of Pakistan along with a continuous breeding program to bring genetic characteristics at par with our requirements.

In research programs, the entire chain from planting through product should be studied, including primary production, harvesting, storage and processing technologies, product development and evaluation, marketing studies and economics. A multidisciplinary approach is needed, with both the public and private sectors as participants. Plant characteristics advantageous for the adaptation of quinoa to other growth regions of the world are available but are scattered throughout the existing germplasm. Further breeding of quinoa in new regions should concentrate on uniformity, early maturity, high yield, quality aspects and industrial uses of the seed and of specific ingredients. The ideal variety of quinoa for seed production would be one maturing uniformly and early. A growing period of less than 150 days would normally be regarded as beneficial. Quinoa should also have a consistently high seed yield and low saponin content and it should be short and non-branching to facilitate mechanical harvesting. Size, shape and compactness of the inflorescence may be important for the rate of maturation. A large open inflorescence will dry quicker after rain and morning dew than a small, compact one, but it may also be prone to seed scattering. Fodder types should be tall, leafy and late-maturing, with a high dry-matter yield and preferably low saponin content.

Quinoa also may be used as a break crop in crop rotations, because it is not susceptible to cereal diseases and only slightly susceptible to soil-borne nematodes. Considerable variation exists between cultivars for many of the examined characteristics, so that it should be possible through selection and breeding to combine many of the desired characteristics in single cultivars, which in turn, could establish quinoa as a novel crop for agriculture in other parts of the world. Quinoa may be a potential alternative crop for drought-prone and salt-affected areas in Africa and Asia, where these problems have become of increasing significance due to intensified agricultural production. Quinoa's potential to provide high-quality food and thus increase food security and alleviate poverty has led to accelerated research on the development of new food products. Such new products may be quinoa milk and tempeh (as a potential alternative to gene-modified soybean), quinoa protein concentrates (30–40%, based on the embryo and considered a potential product for use in intensive rehabilitation programs for the undernourished) and natural colorants. To conclude with, quinoa holds immense potential as food, feed and oil seed crop for Pakistan, provided a comprehensive program for production technology development and a breeding program to bring desirable genotypes into the hands of farmers is ensured. It amounts to an uphill task for agronomists as well as plant breeders to make the cultivation of this crop profitable. Last but not least, the role of extension workers is vital to make the cultivation of quinoa feasible and government should provide financial resources to researchers for production technology development in Pakistan.

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