Quinoa Farming in a Changing Climate: Sustainability, Challenges, and the Way Forward

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ABSTRACT

Quinoa (*Chenopodium quinoa* Wild.), an ancient pseudo-cereal native to the Andean highlands, has emerged as a promising crop for sustainable agriculture due to its exceptional nutritional qualities and adaptability to stress conditions. Quinoa contains all nine essential amino acids, with protein content ranging from **14–18%**, significantly higher than most cereals. Globally, quinoa production has increased from **80,000 tonnes in 2009** to over **200,000 tonnes in 2023**, indicating rising demand. Its ability to thrive in drought-prone, saline, and marginal soils makes it ideal for climate-resilient farming, particularly in arid and semi-arid regions. In India, pilot projects in Rajasthan and Gujarat have shown yields of **8–12 quintals/ha** under low-input conditions. Despite this potential, challenges such as limited agronomic knowledge outside South America, poor seed availability, and lack of established market chains persist. It also highlights opportunities including quinoa's ability to grow in saline and drought-prone soils, its suitability for organic and low-input farming systems, and its emerging role in food security and income generation for smallholder farmers. The study underscores the need for targeted research, policy support, and capacity-building initiatives

to integrate quinoa into diversified and sustainable agricultural systems worldwide..

INTRODUCTION

Quinoa (*Chenopodium quinoa* wild.) an annual herbaceous plant belongs to the Amaranth family, discovered as a health food by North Americans and Europeans in the 1970's and its popularity has increased dramatically in recent years because it is gluten-free (useful for diabetic patients) and is high in protein. It is cultivated in the world with an area of 126 thousand hectares with a production of 103 thousand tones. Bolivia in South America is the largest producer of quinoa with 46 percent of world production followed by Peru with 42 percent and United States of America with 6.3 percent (FAOSTAT, 2023) In India, quinoa was cultivated in an area of 440 hectares with an average yield of 1053 tones (Srinivasa Rao, 2015).

Fig 1: Images on CRF (Under guidance Dr. Lalit Kumar Sanodiya) Prof. Rajendra Singh (Rajju Bhaiya) University, Prayagraj, UP.

Quinoa has a taproot system and penetrates to a depth of 1.5 m below the surface, protecting it from drought conditions with broad leaves. The inflorescence is 15–70 cm tall in a panicle and rises from the top of the plant and the axils of the lower leaves, usually about 1–2 m erect. According to (Shams and Bhargava *et al.* 2006) quinoa seeds are small with a diameter of about 1–2.5 mm and the weight of 1,000 seeds was 1.4–4.3 g. The growth period of quinoa is between 70 and 200 days and some entries do not mature in some places. Quinoa is a fast-growing plant with alternate, coarse-toothed, triangular to oval leaves and is similar to the common North American weed (Chenopodium album called lamb's quarter or goosefoot). Each inflorescence produces hundreds of small achenes about 2 mm in diameter. Quinoa is an achene (a seed-like fruit with a hard coat) with a variety of colors from white or pale yellow to orange, red, brown and black. It has greater plasticity to adapt to photoperiod, altitude, soil pH etc. It can be grown in temperatures up to 3,900 m above mean sea level and a pH range of 6 to 8.5 and in subtropical to tropical and humid regions. The base temperature of quinoa is 30°C with an optimum temperature of 15-30 °C and can tolerate maximum temperature of 50 °C.

The quinoa crop is usually grown on less fertile soils or marginal lands under moisture stressed conditions which is the limiting factor for growth and development. Under these conditions, optimal nutrient supplementation is obligatory to reduce the effects of soil nutrient status and promote good plant growth. However, quinoa is highly sensitive to soil nitrogen (Early *et al.* 2005). Therefore, it becomes more important to establish the density of different plants with respect to its

growth and productivity and the differences in nutrient management.

PACKAGE AND PRACTISES

Soil: It suits well in loamy soil having good drainage and high organic matter content, with moderate slopes and average nutrient content. It prefers neutral soils although it is usually grown in alkaline (up to pH 9) and acid soils (up to pH 4.5).

Seed rate: For commercial planting, 8 to 12 kg/ha of seeds are used since most of the planting is made manually. A desirable population of quinoa plants result from this quantity of seed would be between 100,000 and 160,000 plants/ha. Through seedbeds and transplanting it is possible to reduce seeds to 1-2 kg/ha.

Varieties of quinoa: It has been selected by farmers EC507740 (AICRP UAS Bangalore) themselves or by native or indigenous communities which can be grouped into:

• Small white grain quinoas

• Sweet quinoas, low in saponine

• Bitter quinoas, high in saponine

Climate: It prefers desert, warm and dry, cold and dry, temperate and rainy, temperate with high relative humidity, and Puna grassland and high mountain areas. There are certain varieties or ecotypes adapted to each climate. Water: It is an efficient water user despite being a C3 plant, as it has physiological mechanisms which enable it to avoid moisture and to tolerate and resist a lack of soil moisture.

Temperature: The ideal average temperature ranges around 15-20°C, although it can withstand extreme temperature ranging from 38°C to -8°C.

Radiation: It withstands intense solar radiation enabling it to gain the hours of heat needed to complete its growth and productive period**.**

Photoperiod: There are certain varieties or ecotypes that are short day, long-day or insensitive to photoperiod.

Altitude: It grows from sea level up to about 4,000 meters**.**

Sowing and Seed: Sowing is one of the most important activities because the emergence of seedlings which impacts plant density and final yields depends on this stage. Quinoa seeds are sown at different times, depending on the place to be sown, the variety's traits and soil moisture. Seed rates vary between 6 to 8 kg / ha according to sowing method and spacing. Intercultural Operation in Quinoa Farming When quinoa crop is grown in wide row Spacing, plants branch easily and their growth is hastened as well as the growth of weeds, therefore inter-row cultivation should be carried out. Usually, mechanical weeding is Done in quinoa cultivation. When the plant Attains a height of 20 to 25 cm, first weeding is Done. Thinning is also recommended if the Seedlings are clustered together or need to be Moved to spaces with a greater availability of Water.

Important pests and diseases of quinoa: -

As a crop, quinoa is a newcomer to the world Scenario, and there are lesser studies on specific Pests and diseases. Principle quinoa pests and Diseases deals with two of the most significant Pest complexes, the "noctuid complex" and the "moth complex". Major disease affecting Quinoa on a global scale is downy mildew.

Pest

***Helicoverpa* quinoa:** It is one of the most Common and widespread quinoa pests which

is Responsible for sizeable yield losses up to 20%. It is also reasonable to assume that reports of Quinoa infestations of *H. gelotopoeon* in other Countries involve *H. quinoa*. *Copitarsia incommode: Copitarsia incommode* is one of the principal quinoa's pests, especially in the area around Lake which cause economic Losses of around 30%. The polyphagous Behaviour of this insect, i.e. that it feeds on Various plant species, and the fact that it is Present in many areas around the world, make It a potentially highly destructive pest anywhere Quinoa cultivation is introduced and developed.

Disease

Downy mildew: The disease primarily affects Foliage (leaves), although symptoms may also appear on the stems, branches, inflorescence and grains. Initial symptoms appear on the Leaves as small, irregular spots that may be Chlorotic, yellow, pink, red, orange or grey, Depending on the plant colour. Control The selection of varieties for traits of Resistance, early maturity and large grains Is feasible through breeding. Farming practices Eco-friendly fungicides integrated management and control strategies are practised because every situation is unique and requires different measures for effective.

Control measures

1. **Crop rotation:** Crop rotation is a practice that aims to avoid soil fertility exhaustion and break the pest life cycle because moths overwinter in the pupal stage. Crop rotation Requires that soil be ploughed before planting a new crop in order that the pupae be exposed to Birds and other predators**.**

2. **Light traps**: Light traps are devices which Attract adult moths to capture and kill them. The Basic design is a bright light source and a Capture mechanism containing water and a Small amount of detergent to reduce the surface Tension and prevent the insects from escaping.

3. **Using pheromone traps:** In recent years, Pest management strategies include the use of Pheromone traps to attract male moths. Use of bio-insecticides and eco-friendly

4. **Pesticides**: Bio insecticides and eco-friendly Pesticides are generally used in organic Farming. They are biodegradable and do not Harm the environment. Yield Generally, on an average yield of 500 Kg to 1500 Kg of grains can be expected. However, with proper farm management practices, fertilization and improved varieties, yield of up to 5 tonnes per hectare of quinoa grain can be achieved and green manure or fodder of 5 to 10 tonnes per hectare can be obtained**.**

Challenges

One significant issue is environmental impact. As quinoa cultivation expands beyond its native regions in the Andean plains, farmers face difficulties adapting the crop to different climates and soil types. This expansion can also lead to monoculture practices which may deplete soil nutrients and require increased use of fertilizers and pesticides. Another challenge is the socio-economic impact on traditional quinoa-growing communities. The high demand has driven up prices, benefiting farmers in the short term, but also making quinoa less accessible to local populations who have relied on it as a staple food source. Additionally, the pressure to produce more can lead to over-farming and strain on natural resources. Finally, there's the issue of genetic diversity. As farmers aim for higher yields, they might focus on a few high-performing quinoa varieties, which could reduce the crop's genetic diversity and make it more susceptible to diseases and pests.

Opportunities

Quinoa, often hailed as a "superfood," has been gaining popularity globally due to its high nutritional value, adaptability to various climates, and potential health benefits. In India, quinoa production presents several opportunities:

1. **Growing Demand**: As awareness about healthy eating and superfoods increases, quinoa is becoming more popular among health-conscious consumers in India. This growing demand can create a lucrative market for domestic production.

2. **Climate Adaptability**: Quinoa is well-suited to a range of climatic conditions. It can thrive in semi-arid regions, making it a viable crop for areas in India that face water scarcity or have less fertile soil.

3. **Export Potential**: With quinoa being popular in international markets, Indian farmers could tap into export opportunities. Producing quinoa at a competitive price can attract buyers from countries that are major consumers of this grain.

4. **Crop Diversification**: For Indian farmers, quinoa offers an opportunity to diversify their crops. Diversification can reduce risk and increase resilience against market fluctuations and climate-related challenges.

5. **Government Support**: The Indian government has been encouraging the cultivation of alternative crops, including quinoa, to enhance food security and farmer incomes. Farmers can benefit from various schemes and support systems aimed at promoting quinoa cultivation.

6. **Research and Development**: There is potential for research institutions to develop high-yield and pest-resistant quinoa varieties suited to different Indian agro-climatic zones. This can improve productivity and profitability for farmers.

7. **Nutritional Benefits**: Quinoa is rich in protein, fiber, and essential amino acids, making it a valuable addition to the Indian diet. Promoting its nutritional benefits can drive consumption and support public health initiatives.

CONCLUSION

Sustainable farming of quinoa presents both challenges and opportunities in the modern agricultural landscape. As a highly nutritious and climate-resilient crop, quinoa has the potential to contribute to global food security, particularly in regions facing erratic weather conditions and soil degradation. However, challenges such as limited awareness, high production costs, pest and disease management, and the need for improved agronomic practices must be addressed to ensure its sustainability. Opportunities lie in the growing global demand for quinoa, its adaptability to diverse agro-climatic conditions, and the potential for organic and fair-trade markets. By integrating sustainable farming practices—such as crop rotation, organic fertilization, and water-efficient irrigation—quinoa production can be enhanced while minimizing environmental impact. Additionally, research and policy support, farmer training programs, and investment in value chain development can further strengthen its role in sustainable agriculture. In conclusion, while the path to sustainable quinoa farming involves overcoming certain hurdles, the long-term benefits for farmers, consumers, and the environment make it a promising endeavour. By leveraging scientific advancements, community engagement, and policy interventions, quinoa can play a crucial role in sustainable food systems worldwide.

Fig 2: Field Visit (Harshabardhan M.Sc. Scholar) advisor (Dr. Lalit Kumar Sanodiya), doing infections in the field

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